Construction of Large-Panel
ructures

Report B "Horizontal Joint Tests"

DESIGN AND CONSTRU
LARGE PANEL CONCRETE STR

Contr

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Horizontal Jo

No

FOREWORD

Traditionally, multi-story buildings are so const
if a load-carrying member collapses, the entire
cture does not: it has an inherent structural int
construction using large-panel concrete members is
traditional. Builders cannot necessarily depend c
new structure's inherent integrity.

To avoid potential problems, the Office of Policy
.opment and Research has undertaken an extensive
irch program on large-panel concrete structures.
t, the sixth of nine, deals with horizontal joint
, and most importantly with the connection of
to floors.

The research program was supervised for HUD by th
William J. Werner and continued by Ronald J. Morc
ners, manufacturers, and builders have reason to
eful to them.

Donna E. Shalala
Assistant Secretary for Policy
Development and Research

report describes full-scale tests conducted on horizont
stigate the behavior of wall-to-floor connections in
ctures. Splitting tests were also made to determine the c
einforcement in the ends of the walls to limit splitting
ables included in the test program were strength of grout
nt of transverse wall reinforcement, and presence of
nt and rotation. Effects of test variables on joint stre
ed and a design procedure is proposed.

rimental report on horizontal joints is part of a series
o the development of a "Methodology for the Design and C
Panel (LP) Structures." The objective of the tests de
rt was to investigate the behavior of interior and exteri
nections in LP structures.

ull-scale joint tests and seven splitting tests were ma
consisted of an assembly of precast hollow-core floor
concrete wall elements forming a wall-to-floor connec
represented a short length of wall from a large panel
used to fill the joint between the ends of the floor sla
f vertical load through the joint was investigated by ap
pressive force in increments.

plified splitting tests were made on specimens consis
l element loaded to represent partial surface loading
. The objective was to determine the optimum amount of
nent in the ends of the wall panels to limit splitting.

imental program included the following controlled test va
- strength of grout in the joint,
- amount of transverse wall reinforcement,
- filled or unfilled slab cores, and
- applied floor moment and rotation.

ve strength of concrete used in the wall panels and t
re slab elements was held constant.

upon the provided combination of test variables mentio
ving damage patterns were observed at ultimate load:
- grout crushing,
- wall splitting, and
- slab crushing.

sence of transverse wall reinforcement increases overall strength of connection. The optimum amount of wall reinforcement depende of grout in the joint. With low-strength grouts, the joint str reased substantially by filling the slab cores with grout in the region. However, in the case of high-strength grouts, fillin was only effective if the wall panels were adequately reinf splitting.

lowing conclusions are based on results of the experimental progr

Joint capacity increases with grout compressive strength, joint strength is controlled by grout crushing.

Wall splitting does not occur when low-strength grout is used.

For unreinforced walls, as the grout strength approaches wall pressive strength, the mode of joint behavior changes from crushing to wall splitting. Therefore, grout strengths higher wall strengths do not increase joint capacity unless the wall adequately reinforced. The amount of wall reinforcement req to prevent splitting increases with grout strength.

Filling slab cores with grout directly affects joint strength low strength grouts are used. However, when medium or high str grouts are used, filled cores are effective only if the wall p are reinforced.

Inadequate dry packing below the upper wall panel leads to a stantial loss of joint strength.

Floor moment and rotation do not have a significant effect on capacity.

ussed. A new design procedure is proposed. Comparisons of
ulated strengths for various joint specimens are made.

ion, details of the experimental program and properties of
oints, are included as appendices to the report.

recommendations for specific analysis and design of connec
d in Report 5.

large panel" (LP) concrete structure is used to describe
em composed of precast vertical wall panels with precast fl
anels or planks assembled as shown in Fig. 1. These prefa
buildings can be considered to be the industrialized form
cast-in-place structural wall (egg crate) construction.
dings are differentiated by the general arrangement of load
hown in Fig. 2:

ross wall system: in this most prevalent form, load-beari
alls are perpendicular to the longitudinal axis of the buil

pine wall system: for this form load-bearing walls are
o the longitudinal axis of the structure.

ixed systems: a combination of cross wall and spine wall
s used.

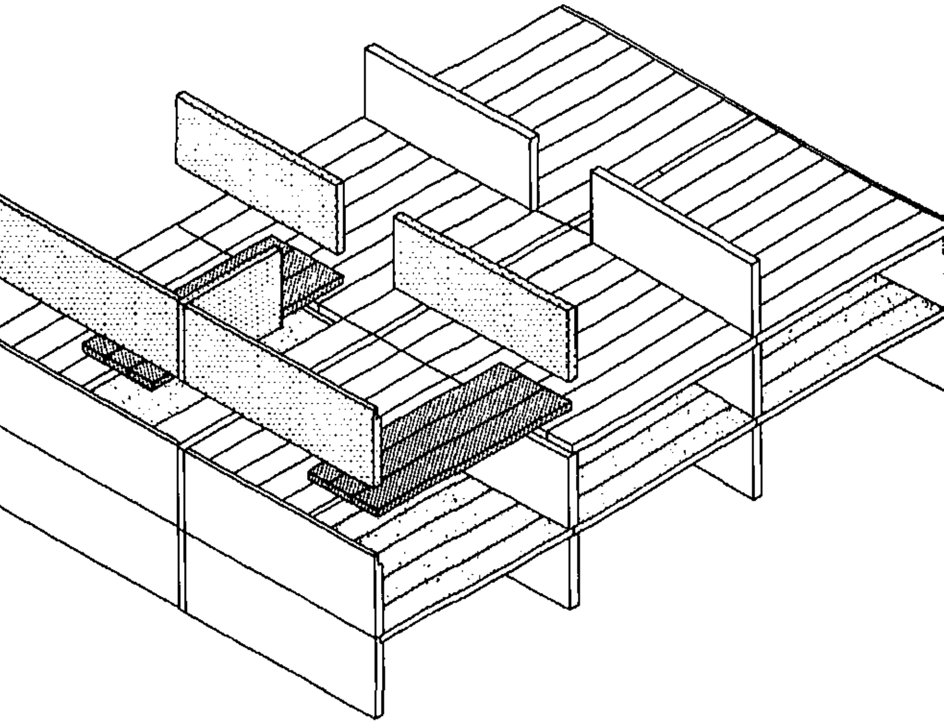
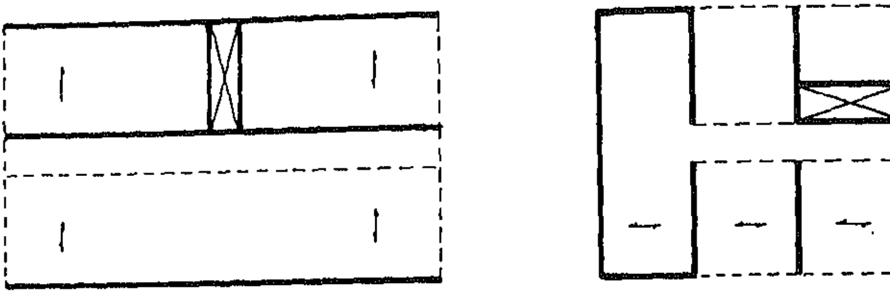


Fig. 1 Isometric View of Idealized Large Panel Structure



(a) Cross Wall System (b) Spine Wall S

Fig. 2 Idealized Plan Arrangement of Structural Wall Pan
Panel Structures

In most LP systems, the walls transfer their loads directly to t
ture without an intermediate frame. This form of construction re
plans at any level. Thus it is most typically suited for multis
where walls have to be provided between apartments to resist fi
transmission. Construction types considered under this investiga
include solid, sandwich, ribbed, hollow core or composite
Solid, hollow core, or ribbed floor units with or without cast-
ping are also included. All elements can be either prestresse
tionally reinforced.

The overall program objective is to develop minimum criteria f
and construction of large panel structures. These criteria are
oped to ensure structural safety and serviceability of LP resid
ings, while also providing minimum performance requirements t
designers and developers of innovative systems. Development of
will also expand the knowledge of design and construction of
structures to a level comparable with that existing for conventi
place concrete or steel structural systems.

structural viewpoint, the essential difference between a co
te structure and a precast large panel structure is the nat
ns between elements. The function of connections is to tran
ne element to another. Ability of large panel structures
actorily under all conditions of loading depends upon the i
nnections. Connections must transmit gravity loads from fl
ts, from wall to wall, and from wall elements to the founda
lso provide for interaction between the various elements a
t ductility in resisting lateral loads. If the connections
strength of the adjoining elements may not be fully utilize

tions may be classified (1) as interior horizontal wal
or horizontal wall-to-floor, horizontal floor-to-floor, a
o-wall. The main objective of the tests described in this
estigate behavior of wall-to-floor connections commonly u
States. The report covers tests of both interior and ext
joints. A single configuration of "Platform Joints"
ssive strength of concrete in wall panels and hollow-core
th of dry-packed mortar below the upper wall panel were he
hout the test series.

ic analysis and design techniques for types of connectio
n LP structures, are presented in Report 5[2].

Details of the test specimens for interior and exterior joint
Figs. 3 and 4, respectively. Controlled variables included in
gram were:

(a) strength of grout in the joint,
(b) amount of transverse reinforcement at the top and b
panels,
(c) filled or unfilled slab cores, and
(d) applied floor moment and rotation.

Design compressive strength of concrete used in the wall p
precast floor slab elements was about 5000 psi (34.5 MPa).

2.1 Test Specimens

Sixteen full-scale wall-to-floor connections and seven s
splitting specimens were tested. In the connection tes
elements consisted of precast concrete hollow-core
elements were blocks of precast concrete. Nominal thick
of floor planks were 8 in. (203 mm) and 24 in. (610 mm),

Detailed descriptions of materials, specimen fabricatior
tion, and test procedures are given in Appendix C.

2.1.1 Specimen JM-1

Before beginning the main test program, Specimen JM-
determine the influence of applied floor moment and
on joint strength. The test was performed using
long slabs on each side of the connection. Test se
arrangement are shown in Fig. 5. Vertical load was
wall in increments by a hydraulic testing machi
rams(3) were used to apply floor moment by apply

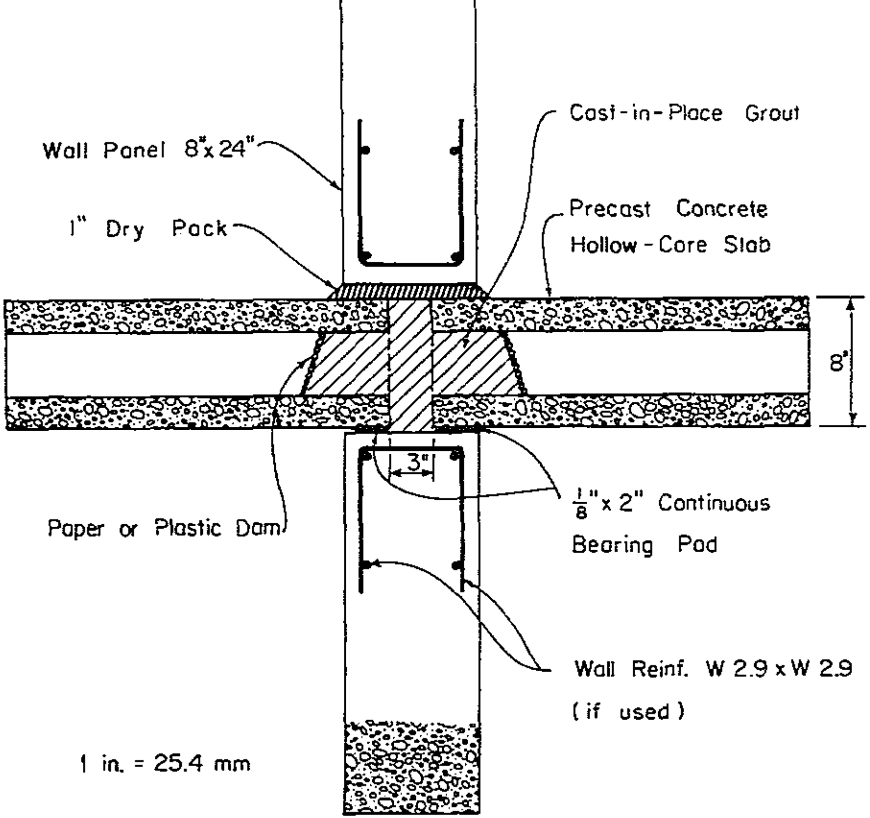


Fig. 3 Interior Joint Specimen

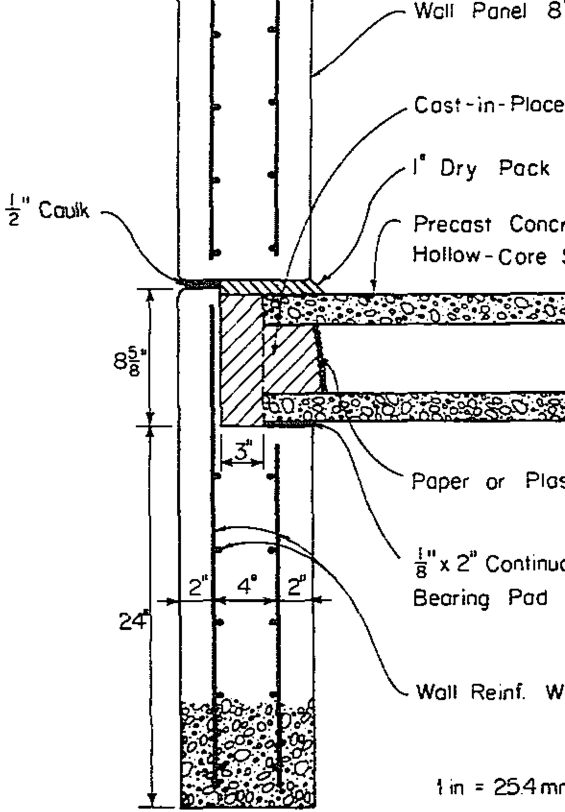


Fig. 4 Exterior Joint Specimen

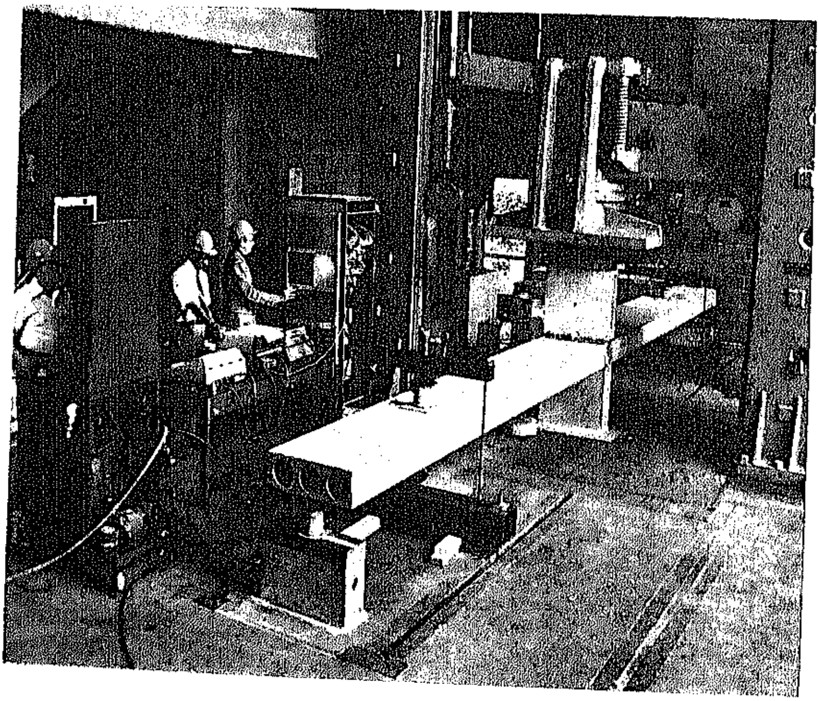


Fig. 5 Test Setup for Specimen JM-1

s(4).

tive moment introduced at the joint was slightly less tha ulated cracking moment for a 24-in. (0.61 m) wide unreinf . Each floor load was positioned at about the third point simply supported end of the slab. This provided a mome r ratio of about 5 at the joint. The figure was based on c ons for a 30-ft. (9.14 m) long slab, assumed fixed at both

Specimen JM-1, grout strength was 3000 psi (20.7 MPa). and bottom walls were unreinforced.

2 Series A - Splitting Tests

tting tests were performed to determine the optimum amou sverse reinforcement needed in the ends of the walls to tting. Wall blocks were plastered to the base of the te ine. Vertical load was applied on top through a 3-in. (7 by 24-in. (610 mm) long steel plate. This loading area onded to the area loaded by the grout column in a com t. Figure 6 shows the test setup for this series. Con ressive strength and amount of reinforcement provided for imen in this series are shown in Table 1.

3 Series J and B - Interior Joint Tests

tests were conducted in Series J and B. Figure 7 shows the . A comparison of test results from trial Specimens JM- indicated that applied floor moment and rotation did not r t strength. Consequently, short slabs, without any ap r moment, were used for the remaining tests. However, the ks were supported at the free ends to prevent rotation.

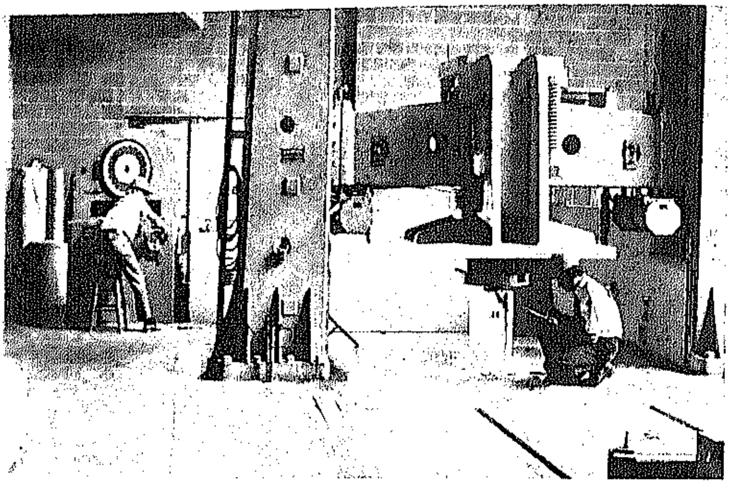


Fig. 6 Splitting Wall Test Setup

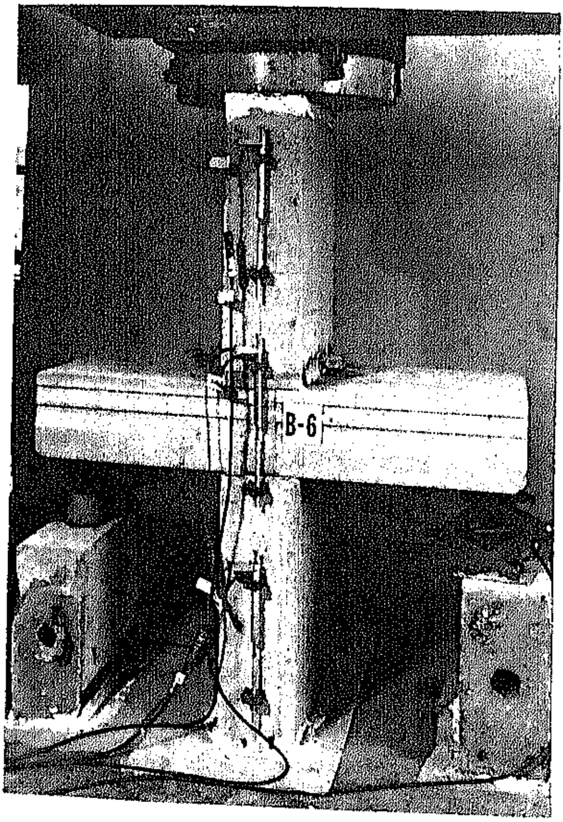


Fig. 7 Interior Joint Test Setup

Specimen Number	Concrete Strength* (psi)	Amount of Wall Reinforcement (in.^{2})	Size of Welded Wire Fabric**
A-1	5040	0	0
A-2	4910	0.041	6x6 - W2.1xW2.1
A-7	5040	0.082	6x6 - W2.1xW2.1
A-3	5040	0.116	6x6 - W2.9xW2.9
A-4	4910	0.144	6x6 - W2.1xW2.1
A-5	4910	0.227	6x6 - W2.1xW2.1
A-6	4910	0.309	6x6 - W2.1xW2.1

*Average compressive strength measured on six 6x12-in. cyli

**6x6-in. mesh with W2.1 and W2.9 wires corresponds to diame
0.162 and 0.192 in., respectively.

Metric equivalents: 1 psi = 6.89 kPa
1 in. = 25.4 mm

Controlled test variables were:

(a) strength of grout in the joint,

(b) amount of transverse wall reinforcement, and

(c) filled or unfilled slab cores.

Grout strength, amount of wall reinforcement and othe
different interior joint tests are given in Table 2.

2.1.4 Series E - Exterior Joint Tests

Details of exterior joint test specimens are shown in
full-scale tests were conducted. Controlled variable
the test program were similar to those for interior
test setup is illustrated in Fig. 8. The layout of i
was similar to the interior joints.

Grout strength, amount of wall reinforcement and othe
exterior joints are given in Table 3.

Wall Panel Concrete Strength* (psi)	Grout Strength* (psi)	Amount of Wall Reinf.** (in.^{2})	Slab Cores Filled or Unfilled	
4860	3000	0	Filled	Po Dr
4860	3000	0	Filled	
5380	2730	0	Unfilled	
5380	3240	0.116	Unfilled	
5420	2980	0	Filled	
5310	3260	0.116	Filled	
4810	4510	0.116	Unfilled	
4820	5000	0	Filled	
4820	5000	0.116	Filled	
5310	6800	0.116	Filled	
4810	4510	0.116	Filled	

compressive strength measured on nine 6x12-in. cylinders.

9xW2.9, four cross wires per wall, A_s = 4x0.029 = 0.116 in.

n with long slabs and applied floor moment.

Equivalents: 1 psi = 6.89 kPa.
1 in = 25.4 mm

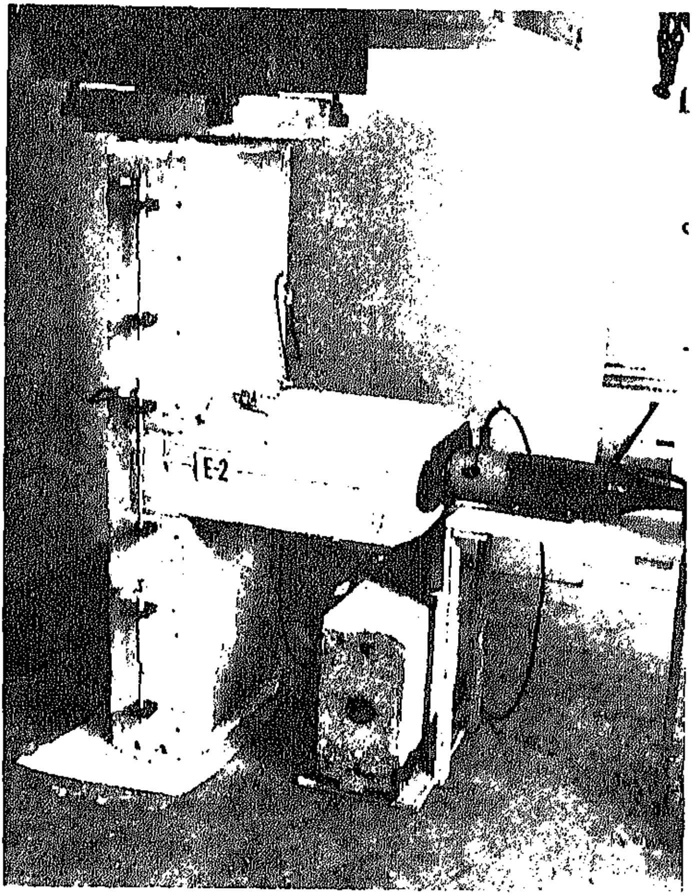


Fig. 8 Exterior Joint Test Setup

Specimen Number	Wall Panels Concrete Strength* (psi)	Grout Strength* (psi)	Amount of Wall Reinf.** (in.^{2})
E-1	5420	2980	0
E-2	5180	2840	0
E-3	5180	4770	0
E-4	4900	4630	0
E-5	4900	4510	0.116

*Average compressive strength measured on six 6x12-in. cyl

**6x6-W2.9xW2.9, four cross wires per wall panel, A_s = 4x0.

Metric Equivalents: 1 psi = 6.89 kPa
1 in. = 25.4 mm

Specimen Strength

red ultimate loads and relevant data are listed in Table
nience, these results are expressed both as ultimate l
as average wall stress. The latter was obtained by divi
ate load by the bearing area of the wall panel. Also
4 are the behavior observations at ultimate load. Th
ssed further in Section 3.3.

red values of the ultimate load versus wall reinforcement
ting test series are shown in Fig. 9. The minimum amount
ment to give slightly higher ultimate load in splitting t
mined as 0.116 in.^{2} (75 mm^2). This reinforcement wa
cient to limit wall splitting in the subsequent joint te
o medium strength grouts were used.

Joint Shortening

tion of vertical shortening, top wall horizontal strain, a
l crack widths with applied loads for Specimen J-2 are
10, 11, and 12, respectively. Average vertical strain f
all panels was calculated by dividing the total shortenin
using LVDT's(3) by the 10 in. (254 mm) gage length. P
tests showed similar trends.

shortening is due to compression of the grout column and t
end of each of the floor slabs. Grout strength had a majo
on the amount of shortening. Overall shortening was gre
trength grouts. For similar conditions of grout strength
orcement, joint shortening in specimens with unfilled sl
t least 33% higher than those with cores filled. Transver
orcement reduced measured wall shortening. This was prob
creased splitting in reinforced wall panels.

Specimen Number	Ultimate Load P_u (kips)	Average Wall Stress** (psi)	Wall Panel Concrete Strength (psi)	Grout Strength (psi)	Slab Cores Filled or Unfilled	Observations at Ultimate Load	Remarks
JM-1	350	1820	4860	3000	Filled	Wall Splitting$^+$	Poor Dry Packing (inadequately packed)
J-1	300	1560	4860	3000	Filled	Wall Splitting$^+$	
B-6	343	1790	5380	2730	Unfilled	Grout Crushing	--
B-7*	360	1870	5380	3240	Unfilled	Grout Crushing	--
B-5	440	2290	5420	2980	Filled	Grout Crushing & Wall Splitting	Both Upper & Lower Walls Split
B-2*	460	2400	5310	3260	Filled	Grout Crushing	--
B-3A*	440	2290	4810	4510	Unfilled	Grout Crushing	--
J-2	465	2420	4820	5000	Filled	Wall Splitting$^+$	--
J-3*	520	2710	4820	5000	Filled	Grout Crushing	--
B-4*	525	2730	5310	6800	Filled	Lower Wall Splitting	Upper Wall & Grout Uncracked
B-1*	266	1380	4810	4510	Filled	Slab Crushing	No Grout Column, Slab Cores Filled

*Wall Panels reinforced with 6x6 - W 2.9 X W 2.9, A_s = 0.116 in.^{2}

**Average wall stress obtained by dividing

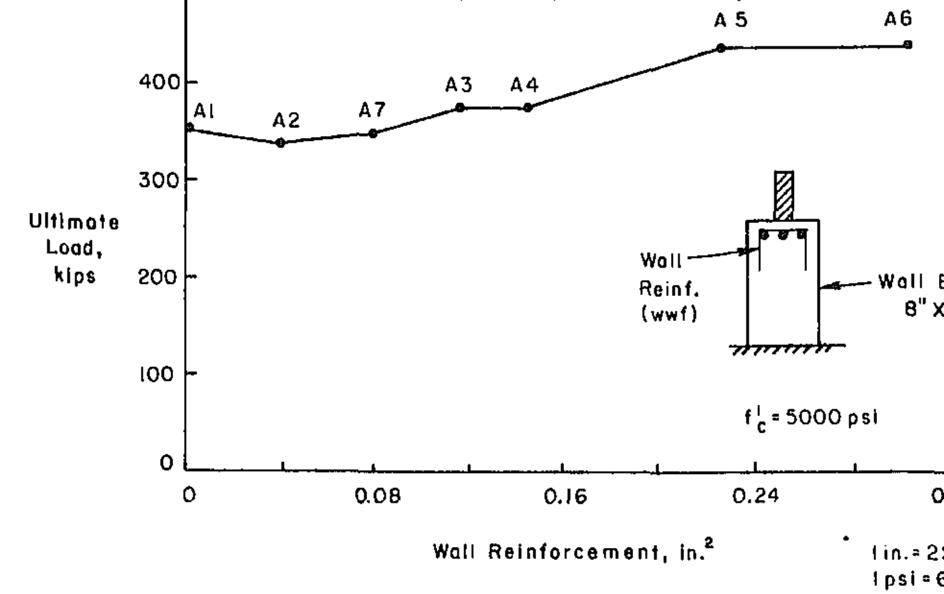


Fig. 9 Splitting Tests - Series A

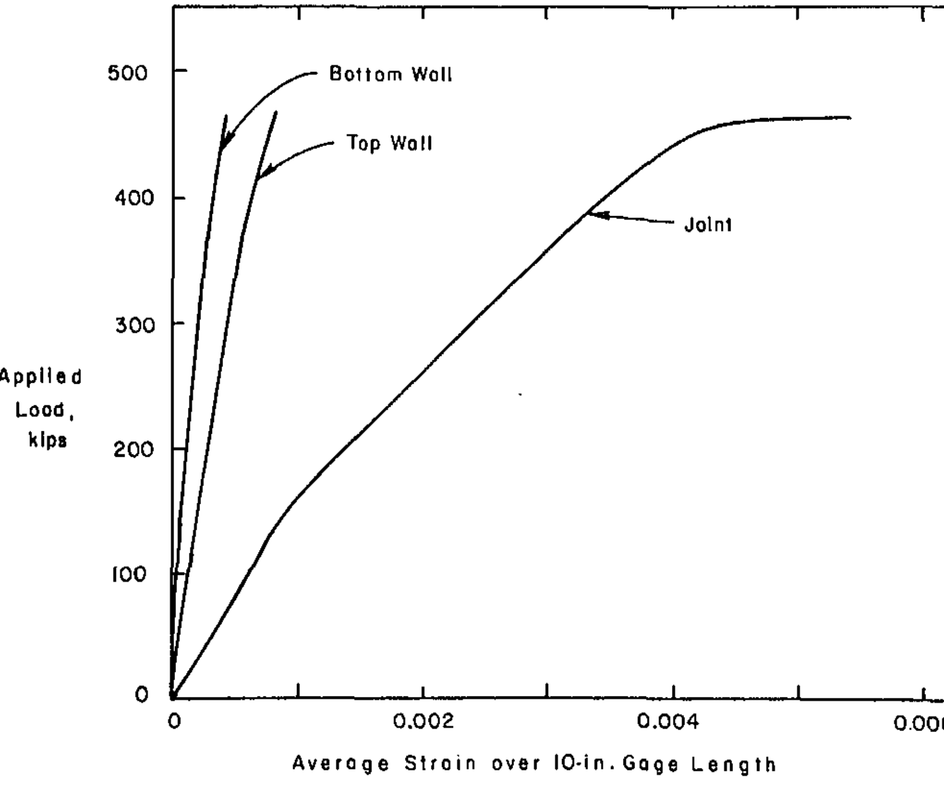


Fig. 10 Load versus Shortening for Specimen

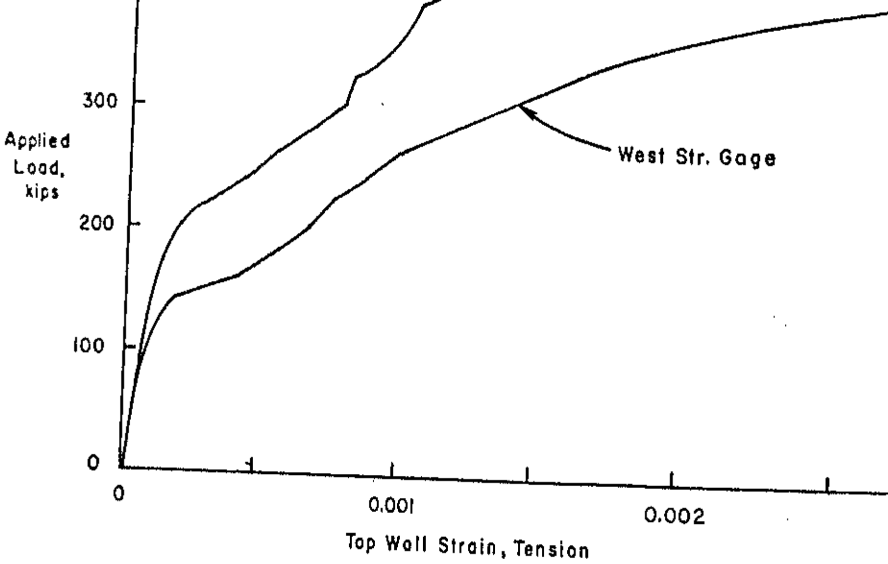


Fig. 11 Load versus Top Wall Strain for Specimen J-2

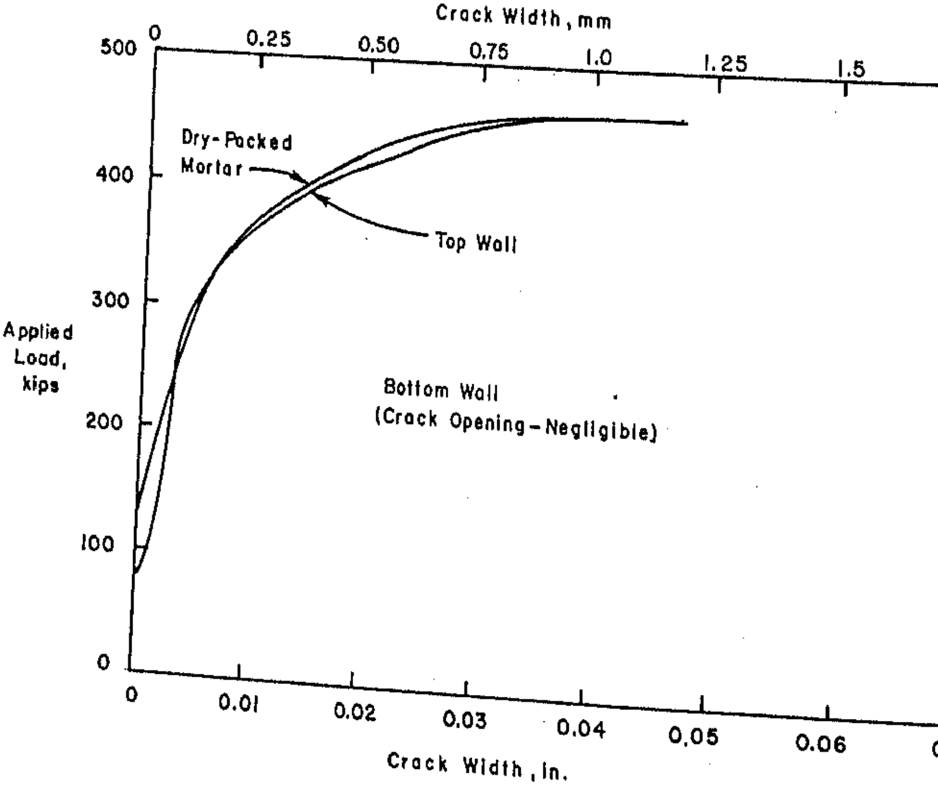


Fig. 12 Load versus Wall Separation for Specimen J-2

l load can pass through an interior joint from the upper w
er wall in either of two distinct fashions.

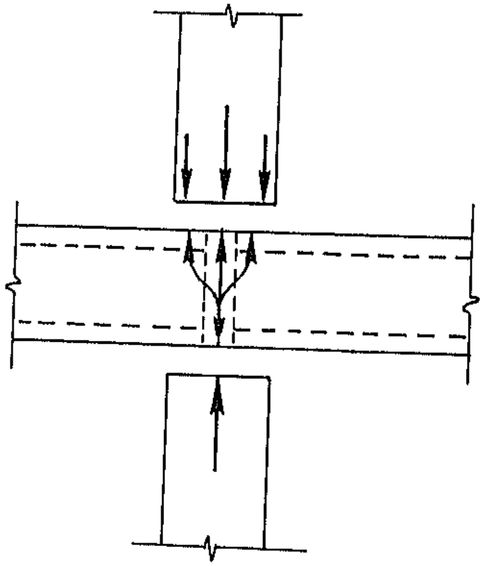
first case shown schematically in Fig. 13(a), the joint fu
nolithic fashion. Stresses across the top of the joint a
t part uniform. However, due to soft bearing pads bene
the load is funnelled into the bottom of the grout column
s concentration in the lower portion of the joint as shown.
s are transferred at the slab-grout column interface.

second case, shown schematically in Fig. 13(b), the joint c
e distinct vertical "columns": a grout column in the cente
n on either side. The outer columns consist of the su
nd bearing pads. The amount of load that each "column" s
with the stiffness of that column in relation to the
Uniform material properties produce generally uniform s
the joint, while greatly differring properties cause
rations.

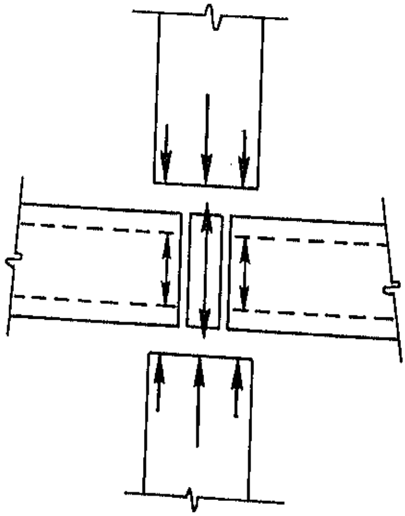
particular interior joint, load flow patterns and behavi
d by four variables:

Compressive strength of the grout as related to the c
sive strength of the wall and slab concrete is one va
For purposes of discussion, "low", "medium", and
strength grouts are defined as having compressive str
respectively, less than, equal to and greater th
strength of the slab and wall concrete. The slab a
concrete are assumed to have equal strength.

Extension of the grout into the hollow cores of the s
another variable. Hollow cores are considered filled
grout extends at least to the plane of the face of the w



(a) Before Cracking



(b) After Cracking

Fig. 13 General Behavior - Interior Joints

verse welded wire fabric as shown in Fig. 3.

Stress level in the joint is a fourth variable.

ects of these variables are discussed in the following sect

3.1 Case 1: Low Strength Grout, Cores Unfilled, Walls Rei or Unreinforced

r Case 1 shown in Fig. 14(a) load flow is through discrete l columns. Since the slab cores are unfilled and the slab lves are supported on soft bearing pads, the grout co dependent of the slab and carries most of the load. With rength less than the wall strength, increasing load p out column crushing, identified as Stage 1. With the loss out column, load is transferred to the two slab ends. eir lower net area these eventually crush before damagi ll. This is identified as Stage 2. Since the capacity out column is generally greater than that of the combin ds, maximum capacity is reached at Stage 1.

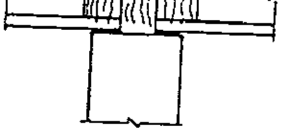
resses in the wall panels never control. Consequentl navior and capacity of this joint configuration are not a reinforcing. This behavior was observed in Specimens B 7. Specimen B-6 after testing is shown in Fig. 15(a).

3.2 Case 2: Low Strength Grout, Cores Filled, Walls Reinf or Unreinforced

Case 2 with filled cores as shown in Fig. 14(b), the haves initially as a monolithic element. The funnelling accomplished through shear between the grout column a out cores. Vertical stress is initially uniform at the

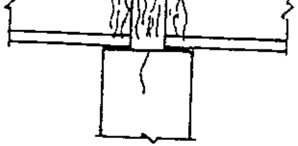
(a) Low strength Grout, Cores Unfilled, Walls Reinforced or Unreinforced

*1 - Grout Crushes
2 - Slab Ends Crush



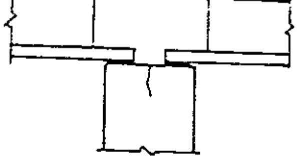
(b) Low Strength Grout, Cores Filled, Walls Reinforced or Unreinforced

1 - Grout Cores Shear Off
*2 - Grout Crushes
3 - Slab Ends Crush



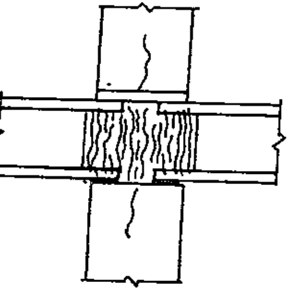
(c) Medium Strength Grout, Cores Unfilled, Walls Reinforced or Unreinforced

1 - Both Walls Crack
*2 - Grout Crushes
3 - Slab Ends Crush

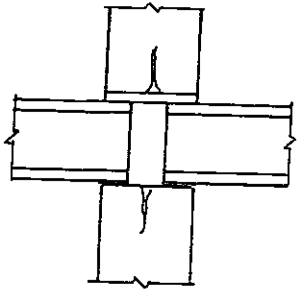


(d) Medium Strength Grout, Cores Filled, Walls Unreinforced

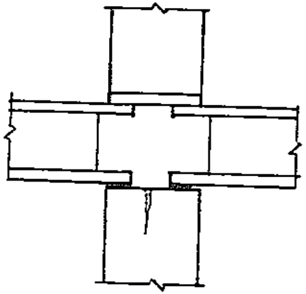
1 - Grout Cores Shear Off
2 - Both Walls Crack
*3 - Upper Wall Splits



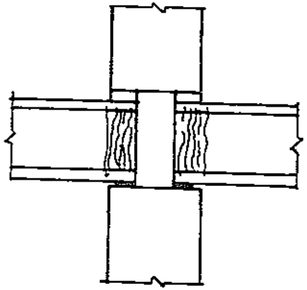
e) Medium Strength Grout, Cores Filled, Walls Reinforced



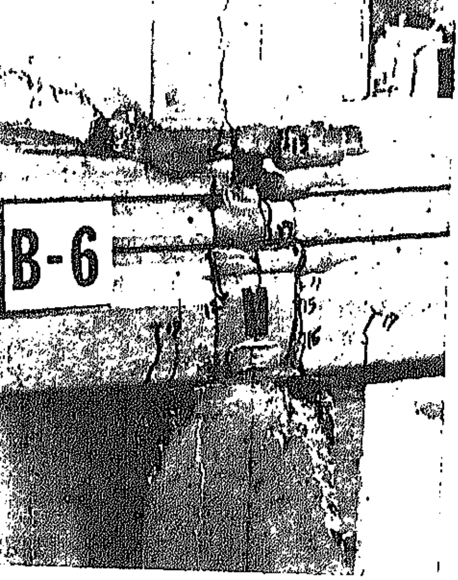
(f) High Strength Grout, Cores Unfilled, Walls Reinforced or Unreinforced



(g) High Strength Grout, Cores Filled, Walls Reinforced or Unreinforced



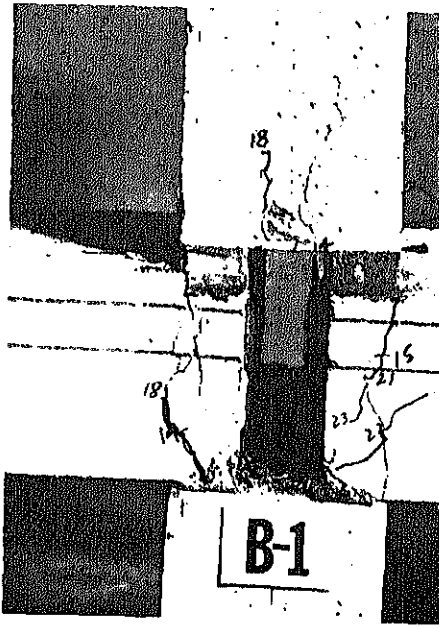
(h) No Grout in Joint, Walls Reinforced or Unreinforced



Grout Crushing

(b) Upper Wall Split

c) Lower Wall Splitting



(d) Slab Crushing

Fig. 15 Damage Patterns at Ultimate Load - Interior Jo

grout column. This is identified as Stage 1.

Following Load Stage 1, the load flow is through d
columns. Due to the soft bearing pads under the
grout column carries most of the load. With grou
than wall strength, increased load produces
identified as Stage 2, and load is transferred to
Although the slab ends have additional strength du
cores, they are still weaker than the wall element
the slab ends is the final stage. This type
evident in Specimens B-2 and B-5. Secondary split
also occurred in Specimen B-5, shown in Fig. 15(b)
the maximum joint capacity is reached when grout
Stage 2. Stresses in the wall panels never t
consequently reinforcing does not affect behavior
this joint configuration.

3.3.3 Case 3: Medium Strength Grout, Cores Unfille Reinforced or Unreinforced

For Case 3 shown in Fig. 14(c), load flow is throu
tical columns. The soft bearing pads and unfill
slab ends cause the grout column to support most of
leads to vertical stress concentrations at the wa
duces horizontal tensile stresses in the walls.
cracks the upper and lower walls, identified as S
increase in load, however, causes grout crushing be
splits. This is identified as Stage 2. Grout crus
by load transfer to the slab ends and eventual sl
identified as Stage 3. The capacity of the grout c
than that of the combined slab ends. As a result,
reached at Load Stage 2.

vior and capacity of the joint are not expected to be ch
reinforcing. Specimen B-3A containing reinforcement exhi
behavior.

4 Case 4: Medium Strength Grout, Cores Filled, Walls Unreinforced

Case 4 shown in Fig. 14(d), grouted cores cause the joi
ond initially as a monolithic element. Vertical stres
orm at the top of the joint and concentrated in the
mn at the bottom of the joint. As load is increased,
city of the medium strength grout cores is reached and
t cores are sheared off from the grout column. Thi
tified as Stage 1.

owing Stage 1, load flow is through discrete vertical col
grout column carries most of the load, but not as much a
3. This is due to the increased stiffness of the grouted
cores versus the ungrouted cores in Case 3. The vertical s
entrations at the wall ends caused by the grout column i
ile stresses in the walls. Increased load causes crack
the upper and lower walls. This is identified as Stage 2.

the same total vertical wall load, the grout column in this
slightly lower stress than in Case 3. The difference is e
split the unreinforced walls, identified as Stage 3. Thi
or was observed in Specimen J-2, where the upper wall split

5 Case 5: Medium Strength Grout, Cores Filled, Walls Reinforced

joint configuration, shown in Fig. 14(e), is identical to
ase 4 with the exception of the addition of transverse spli
forcing in both upper and lower wall panels. Behavior is
tical to that of Case 4 through Load Stage 2. As the lo

the slab ends which also eventually crush. This is ident Stage 4. The capacity of the grout column confined betwee ends, is generally higher than that of the combined gr ends. Therefore, ultimate capacity is reached when gro shed at Stage 3. This behavior was observed in Specimen J-3

6 Case 6: High Strength Grout, Cores Unfilled, Walls Reinforced or Unreinforced

Case 6 shown in Fig. 14(f), no specimen was tested. How d on observations from the other tests, the behavior c cipated. Load flow is through discrete vertical columns. bearing pads and unfilled cores of the slab ends caus t column to support most of the load. The grout column er strength than the wall. Consequently, horizontal te sses in the walls, due to the vertical stress concentra d become critical long before the grout column capaci hed. Increased load first cracks the upper and lower then splits them. This is identified as Stages 1 and 2 tively. Splitting will occur whether or not the wall nally reinforced.

7 Case 7: High Strength Grout, Cores Filled, Walls Reinfo or Unreinforced

Case 7 shown in Fig. 14(g), The grouted cores cause the espond as a monolithic element. Vertical stress is unif top of the joint and concentrated in the grout column om of the joint. Under increasing load, the grout cores off the grout column because of the increased shear ca he high strength grout. Instead, the vertical stress c ion at the bottom of the joint causes horizontal tensile dup in the lower wall. These latter stresses become cr

ntified as Stages 1 and 2, respectively. Splitting will
ther or not the walls are nominally reinforced. This be
observed in Specimen B-4, shown in Fig. 15(c).

.8 Case 8: No Grout in the Joint, Walls Reinforced or Unreinforced

e 8, shown in Fig. 14(h), represents an extreme limit of C
d flow is solely through the outside slab ends. Capacity o
nt is reached as the slab ends crush, identified as Sta
esses in the wall panel never become critical, consequentl
avior and capacity of the joint are not altered by reinfo
s behavior was observed in Specimen B-1, shown in Fig. 15(d

ect of Variables on Joint Strength

cts of variables on interior joint strength may be summari

A change in a variable to cause a more uniform ve
compressive stress across the width of the joint gen
increases the vertical load-bearing capacity of the joint

Under certain circumstances, control of vertical cracki
walls increases the vertical load carrying capacity o
joint.

the variables examined, a list of interior joint configur
in Table 5. The purpose of the table is to list the join
ons in ascending order of capacity. Behavior of joint conf
at were not tested have been estimated.

TABLE 5 - INTERIOR JOINT CONFIGURATION IN ASCENDING ORDER OF CAPACITY

Specimen	Joint Configuration	Strength of Grout	Cores Filled	Walls Reinforced	Behavioral Case	Behavior at Ultimate
B-1	JC1	No Grout	No	Either	8	Slab End Crushing
B-6, B-7	JC2	Low	No	Either	1	Grout Crushing
B-2, B-5	JC3	Low	Yes	Either	2	Grout Crushing
B-3a	JC4	Medium	No	Either	3	Grout Crushing
-	JC5*	High	No	No	6	Wall Splitting
J-2	JC6	Medium	Yes	No	4	Wall Splitting
-	JC7*	High	No	Yes	6	Wall Splitting
-	JC8*	High	Yes	No	7	Wall Splitting
J-3	JC9	Medium	Yes	Yes	5	Grout Crushing
B-4	JC10	High	Yes	Yes	7	Wall Splitting

*Rank estimated based on test results for other spe...

ut strength ranging from about 2700 psi to 6800 psi (18.6 M
9 MPa) had a significant effect on joint strength. Mea
imate loads versus grout strengths for test specimens are
Fig. 16. It can be seen that joint strength generally incr
h grout strength, provided the capacity was controlled by
shing. However, as indicated in Table 5, for joint confi
h JC10, high strength grout alone did not ensure greater
acity. As shown in Fig. 16 for Specimen B-4, joint strengt
trolled by wall splitting, and grout strength was never reac

2 Transverse Wall Reinforcement

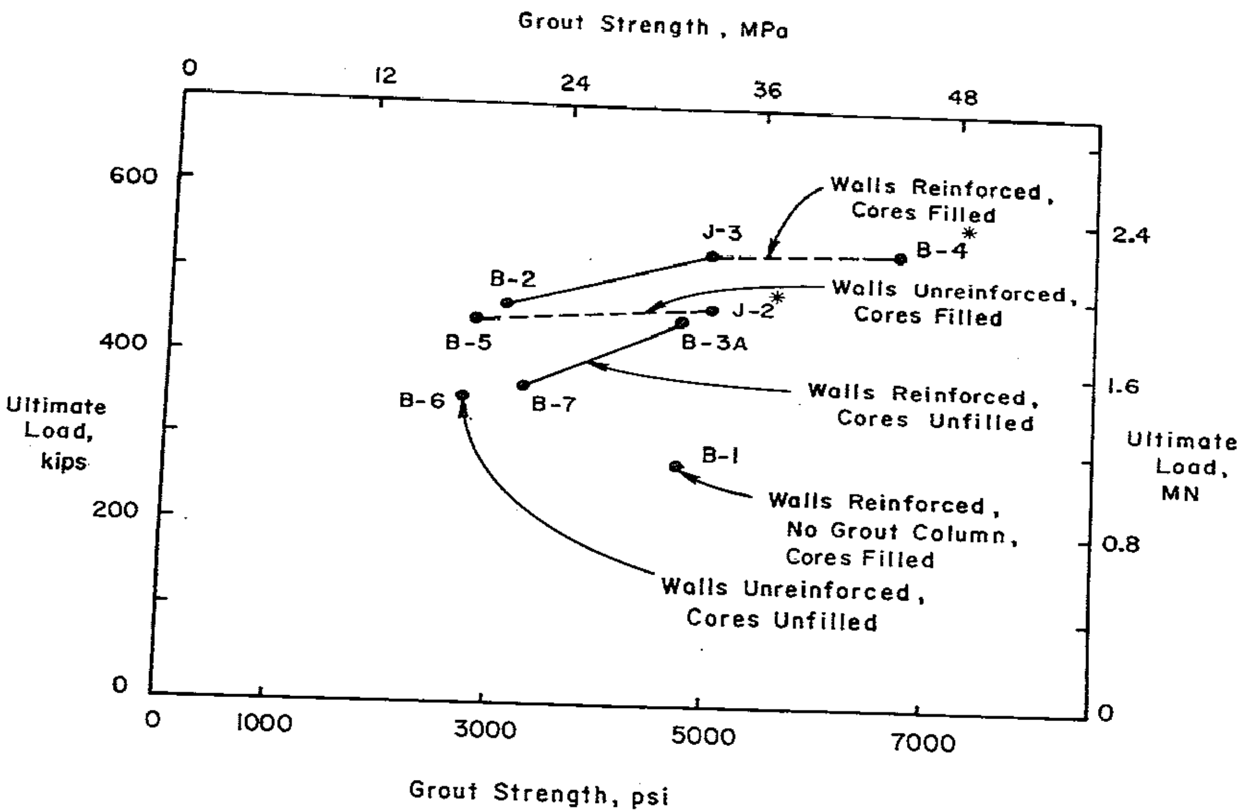
t resisting reinforcement had no effect on strength in
figurations JC1 through JC4. In these configurations,
engths were controlled by grout crushing. This is shown i
st four joint configurations of Table 5. Reinforcement incr
capacity when the strength was controlled by wall splitti
unreinforced wall. This corresponds to joint configuration
JC9 and was observed in Specimens J-2 and J-3.

3 Filled Slab Cores

similar conditions of grout strength and wall reinforce
filled cores in the connection region increased joint capa
ed cores increased the stiffness of the slab ends thereby
uting to a more uniform vertical stress distribution in
t. Consequently, crushing of the grout occurred at h
s.

4 Applied Floor Moment and Rotation

eral loading conditions were used to determine the influen
nt and rotation on joint strength. The intensity of co
ed floor load was such that the negative moment introduc



Grout Strength, MPa
0
12
24
36
48
600
400
200
0
Ultimate Load, kips
2.4
1.6
0.8
0
Ultimate Load, MN
Walls Reinforced, Cores Filled
J-3
B-4*
B-2
Walls Unreinforced, Cores Filled
J-2*
B-5
B-3A
B-6
B-7
Walls Reinforced, Cores Unfilled
B-1
Walls Reinforced, No Grout Column, Cores Filled
Walls Unreinforced, Cores Unfilled
0
1000
3000
5000
7000
Grout Strength, psi

io of about 5 at the joint. The results indicate that
ent and rotation do not affect joint strength signific
ation does induce some tensile splitting forces into the
l. However, the effect is minimal and generally ca
lected.

.5 Dry Packing

addition to the variables discussed above, joint performanc
luenced significantly by the uniformity of dry-packed r
ow the upper wall panel. Well-packed mortar lead to ur
esses below the upper wall. Poor dry packing lead to nonur
esses, thereby substantially reducing joint strength d
mature splitting of the upper wall.

erimental Determination of "Stiffness Factor"

compressive load applied to the upper wall panel is trans
ower wall panel through the grout column between the floor
slabs supported on the bearing pads. A greater part of the
, however, takes place through the grout column. The perce
transferred through different elements in a horizontal jo
on of the relative stiffness of each element in relation
iffness of the connection. Stress flow in the slabs is
h across the slab depth and in the direction of the floor
e, the effective plank stiffness is indeterminate and
erial properties, load pattern, and geometry of connection.
is considered based on measurements made on joint shor
t column shortening.

.1 Joint Shortening

nt shortening was measured over a height of about 10.6
0 mm). This distance included grout column, dry pack, and
in. (19 mm) each of top and bottom walls.

osely represents conditions in the joint after vertical cracki
kes place at the end of each floor element separating the gro
umn from the grout in the slab cores. Each discrete column
nsidered to act independently.

ng the notation given in Fig. 17(a),

$$\sigma = \frac{\delta\ell_1}{\ell_1} E_1 = \frac{\delta\ell_2}{\ell_2} E_2 = \frac{\delta\ell_3}{\ell_3} E_3 = \frac{\delta\ell_4}{\ell_4} E_4 \qquad \text{(Eq. B-}$$

$$\delta\ell_3 = \delta\ell - \delta\ell_1 - \delta\ell_2 - \delta\ell_4$$

$$= \delta\ell - \sigma\left(\frac{\ell_1}{E_1} + \frac{\ell_2}{E_2} + \frac{\ell_4}{E_4}\right) \qquad \text{(Eq. B-}$$

ere σ = uniform vertical stress in column,

$\delta\ell_2$, $\delta\ell_3$, $\delta\ell_4$ = shortening over heights ℓ_1, ℓ_2, ℓ_3, ℓ_4 of Elements 1, 2, 3, 4, respectively,

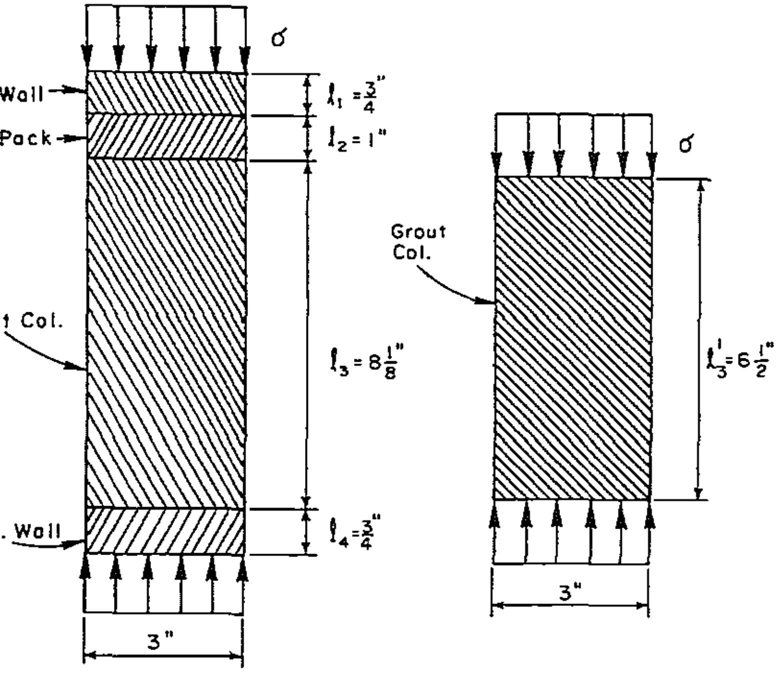
$\delta\ell$ = measured joint shortening = $\delta\ell_1 + \delta\ell_2 + \delta\ell_3 + \delta\ell_4$, and

E_1, E_2, E_3, E_4 = modulus of elasticity of Elements 1, 2, 3, respectively.

shortening in grout column, $\delta\ell_3$, was determined from the ab
pression by assuming a uniform vertical stress, σ, and using
responding values of E_1, E_2 and E_4 from a family
ress-strain curves plotted for materials of different compress
engths. A trial and error method was used to match the assu
rtical stress with the grout column stress corresponding to c
ated grout column shortening $\delta\ell_3$.

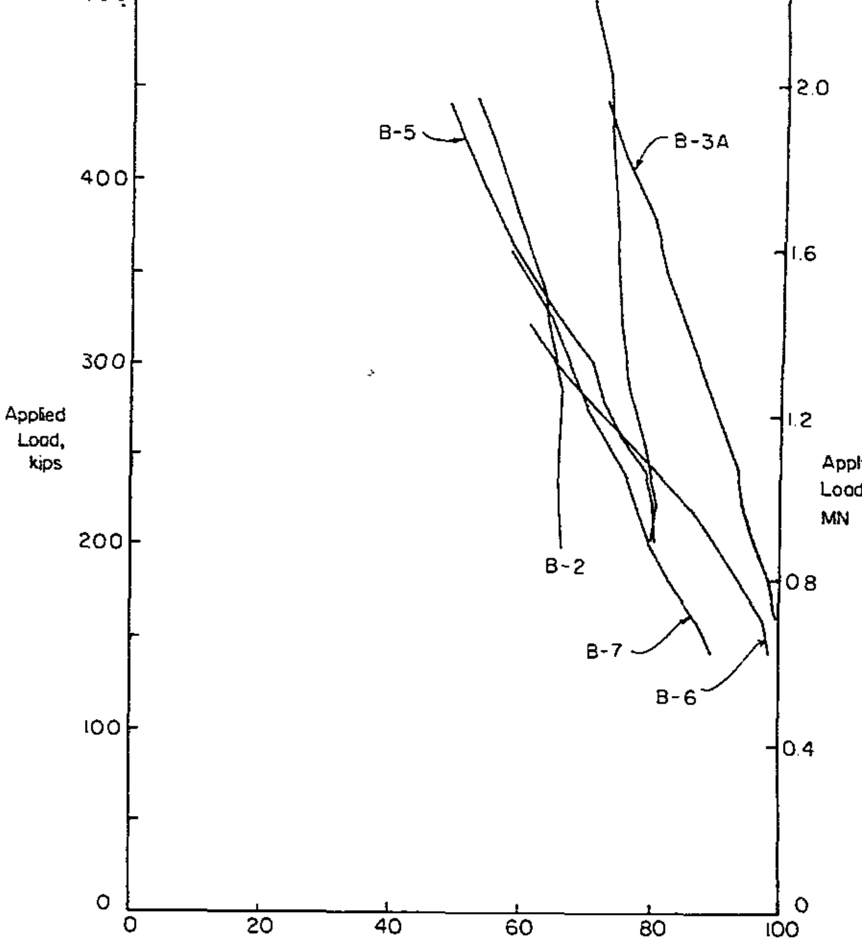
erefore, the amount of load transferred through the grout colu
is given by:

$$P_g = \frac{\delta\ell_3}{\ell_3} (E_3) (A_g) \qquad \text{(Eq. B}$$



(a) Joint Shortening

(b) Grout Column Shortening



where g

3.5.2 Grout Column Shortening

Stress analysis based on total joint shortening described in Section 3.5.1 was quite complex. It involved materials with different elastic properties. The voids left between different materials as a result of construction procedures and subsequent shrinkage were not considered in the analysis. This resulted in a high calculated percentage of load transferred through the grout column in the initial load stages.

Shortening in the grout column alone was also measured in Specimens B-6 and B-7. Strain measurements were taken over a height of about 6.3 in. (160 mm).

Assuming a uniform stress throughout the length of the grout column as shown in Fig. 17(b), the percentage of applied load transferred through the grout column was calculated.

$$\sigma = \frac{\delta \ell'_3}{\ell'_3} E_3 \qquad \text{(Eq. 8}$$

where $\delta \ell'_3$ = shortening over height ℓ'_3 of grout column

Therefore, the amount of load transferred through the grout co

is given by:

$$P_g = \frac{\delta \ell'_3}{\ell'_3} (E_3)(A_g) \qquad \text{(Eq. 9}$$

Using the procedure described in Sections 3.5.1 and 3.5.2, the

centage of load transferred through the grout column was calcul

ized column by cracking at the slab end and grout col
face. Results for Specimens J-3 and B-4 are not plotted
inconsistent data. Figure 18 shows that the percentag
transferred through the grout column decreased as the
increased.

Specimen Strength

mate test loads are given in Table 6. For convenience, these res expressed both as ultimate load, P_u, and as average wall str latter was obtained by dividing the ultimate load by the bea of the wall panel. Also given in Table 6 are the observation mate load indicating that crushing of the grout occurred in imens.

General Behavior

in interior joints, vertical load can pass through an exterior j either of two fashions. In the case shown schematically in a), the joint functions in a monolithic manner. Load is distrib oss the top, nonuniformly due to the built-in eccentricity of nt. At the bottom of the joint, load is funnelled into the g umn due to the soft bearing pads beneath the ends of the slabs.

the case shown in Fig. 19(b), the joint consists of two discrete al "columns": a grout column in the center and a column on one sisting of the end of the slab. The load that each "column" supp ies with the total stiffness of that column and the eccentric sent within the exterior joint. As there exists a signif lt-in eccentricity because of the discrete slab end on only one form material properties will not produce uniform stresses across nt, as in the case of interior joints.

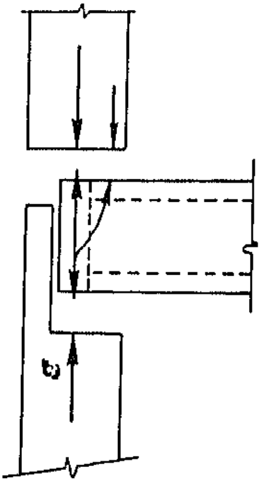
a particular exterior joint, both load flow patterns and beh governed by the same four variables as interior joints describ tion 3.3. However, in exterior joints the effects are much less nced. As noted above, the basic configuration of the joint lea uniform stresses no matter what the material properties may be wn schematically in Fig. 19(c), the joint initially tends to tra of the load to the centrally located grout column. Conseque

TABLE 6 - TEST RESULTS-EXTERIOR JOINTS

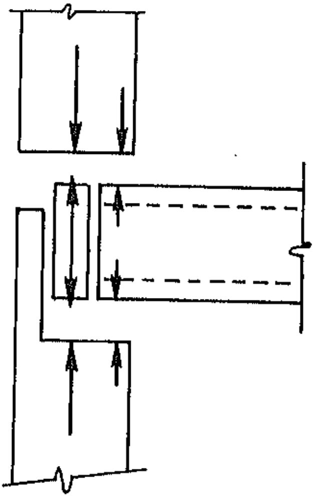
Specimen Number	Ultimate Load P_u (kips)	Average Wall Stress** (psi)	Wall Panel Concrete Strength (psi)	Grout Strength (psi)	Slab Cores Filled or Unfilled	Observations at Ultimate Load	Remarks
E-1	300	1560	5420	2980	Filled	Grout Crushing	--
E-2	290	1510	5180	2840	Unfilled	Grout Crushing	--
E-3	280***	1460	5180	4770	Unfilled	Grout Crushing	Poor Dry Packing (inadequately packed)
E-4	380	1980	4900	4630	Filled	Grout Crushing	--
E-5*	400	2080	4900	4510	Filled	Grout Crushing	--

*Wall Panels reinforced with 6x6 - W 2.9 X W 2.9, A_s = 0.116 in.^{2}

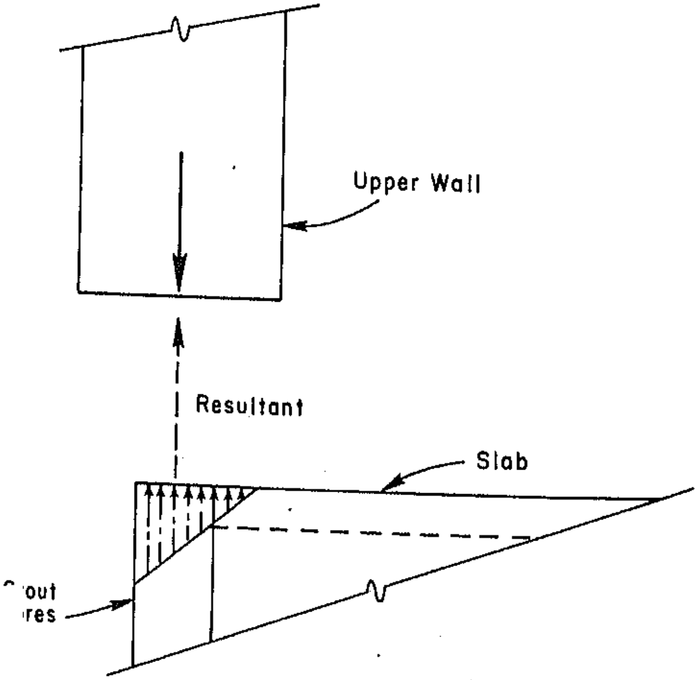
**Average wall stress obtained by dividing the ultimate load by the bearing area of wall panel (bearing area is 24x8 in.)



a) Before Cracking



(b) After Cracking



) Nonuniform Stresses Prior to Ultimate load

General Behavior - Exterior Joints

hen compared to similar interior joints.

.1 Case 1: Low and Medium Strength Grout, Cores Filled or Unfilled, Walls Reinforced or Unreinforced

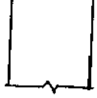
Case 1, shown in Fig. 20(a), load flow is through discrete al columns when cores are unfilled, and through a monol ment when cores are filled. In the latter cases, however ut carries most of the load. As load is increased, the gro shed before tensile splitting stresses, caused by the ver ess concentration, become critical in the wall panel. Th ntified as Stage 1.

n the loss of the grout column, load is transferred to the s, which also crush, identified as Stage 2. Since the cap the grout column is greater than that of the slab end, ma d is reached at Stage 1.

esses in the wall panel never become critical. Therefore avior and capacity of this joint configuration are not al reinforcing. A specimen exhibiting this behavior is show 21. Similar behavior was observed in all specimens at e load.

2 Case 2: High Strength Grout, Cores Filled or Unfilled, Walls Reinforced or Unreinforced

specimens representing Case 2, shown in Fig. 20(b), were te load flow is similar to that of Case 1. Due to the ecce ing of the wall and to the soft bearing pads beneath the , the grout again transfers most of the load. The grout er strength than the wall concrete. Consequently, i cted that horizontal tensile stresses in the walls, due to ical stress concentration, would become critical long be grout column capacity is reached.



a) Low & Medium Strength Grout Cores Filled or Unfilled, Walls Reinforced or Unreinforced

*1 - Grout Crushes
2 - Slab Ends Crush

(b) High Strength Grout Filled or Unfilled, Reinforced or Unrei

1 - Both Walls Cra
*2 - Both Walls Spl

*Ultimate Capacity

Fig. 20 Behavior at Successive Load Stages - Exterior Joi

Fig. 21 Damage Pattern at Ultimate Load - Exterior Joints

ely. Splitting would likely occur whether or not the walls

inally reinforced.

ects of Variables on Joint Strength

rength was the only variable in the test program that influe

of the joint. This occurred because the basic configuratio

t caused most of the load to be transferred through the g

the variables examined, a list of exterior joint detail

Table 7. The table lists joint configurations in ascen

capacity. Behavior of the last two joint configurations

have been estimated.

.1 Strength of Grout

ut strength ranging from approximately 2800 psi to 4800

.3 MPa to 33.1 MPa) had a significant effect on joint stren

sured ultimate loads versus grout strength are shown in Fig

can be seen that with the exception of Specimen E-3, which

rly dry packed, joint strength increased with grout strength

suggested in Table 7 for configuration JC13 and JC14, the

y of joints with high strength grout is expected to be contr

wall splitting.

.2 Transverse Wall Reinforcement

ition of split-resisting reinforcement has no effect on j

h low or medium strength grout. Reinforcement will inc

nt capacity only when the mode of behavior at ultimate is

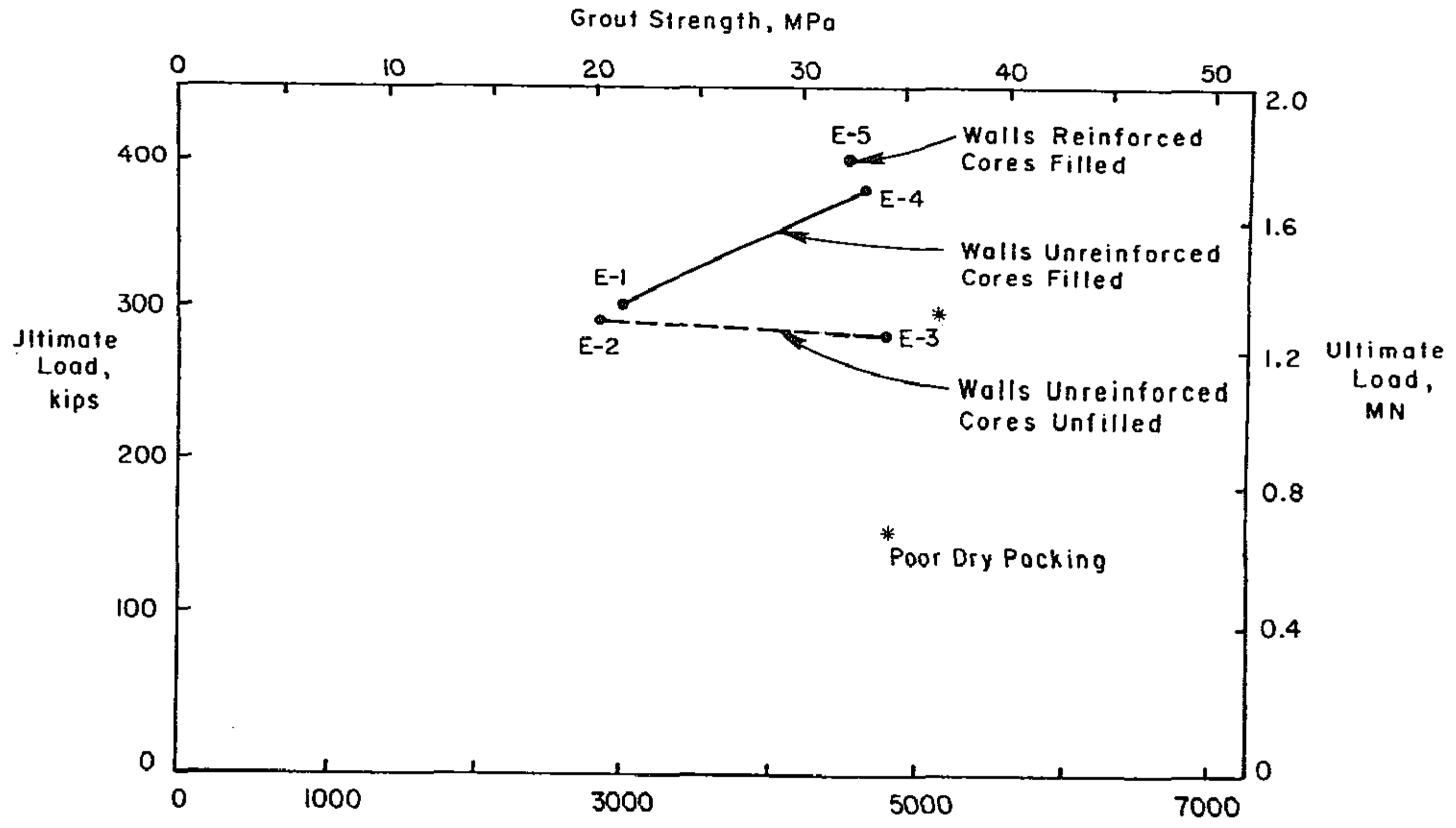
itting in a non-reinforced wall. Joint configurations JC1

4 would be expected to perform this way.

TABLE 7 - EXTERIOR JOINT CONFIGURATION IN ASCENDING ORDER OF CAPACITY

Specimen	Joint Configuration	Strength of Grout	Cores Filled	Walls Reinforced	Behavioral Case	Behavior at Ultimate
E-1,E-2	JC11	Low	Either	Either	1	Grout Crushing
E-3,E-4,E-5	JC12	Medium	Either	Either	1	Grout Crushing
--	JC13*	High	Either	No	2	Wall Splitting
--	JC14*	High	Either	Yes	2	Wall Splitting

*Rank estimated based on test results for other specimens.



Grout Strength, MPa
0
10
20
30
40
50
2.0
1.6
1.2
0.8
0.4
0
Ultimate Load, MN
400
300
200
100
0
Jltimate Load, kips
0
1000
3000
5000
7000
E-5
E-4
E-1
E-2
E-3
Walls Reinforced Cores Filled
Walls Unreinforced Cores Filled
Walls Unreinforced Cores Unfilled
* Poor Dry Packing

capacity. As the exterior joints have a slab on one side of the joint only, lesser load is transferred through the slab as compared to the interior joints. Therefore, filling the c exterior joints will have somewhat less of an effect.

4.3.4 Dry Packing

Poor dry packing can lead to premature joint failure. Dry is more difficult in exterior joints, because mortar has packed from one side of the joint only. Consequently, th ability of inadequate packing is higher.

'restressed Concrete Institute Methods

ent years, several methods to determine the load capacity o
connections in large panel structures have been proposed
n discusses three design procedures proposed by the Pres
te Institute (PCI)[5].

essed Concrete Institute Method 1[5] is based on streng
components. Applied design load on the joint is distrib
omponents of the joint according to the stress-deformati
th characteristics of the components. It also allows a "c
actor" on the cylinder strength of concrete or grout in the

ethod is empirical in nature, and is complex to use. The
perimental data to verify the stress-strain relationships
alysis. Elastic properties of the bearing pads used in the
tests described in this report differed substantially fr
suggested in PCI Method 1.

essed Concrete Institute Method 2[5] is based on
is of a joint. With this approach, the joint is divided
of discrete vertical "columns." The amount of load tha
n" supports is a function of the stiffness of that par
. The method permits determination of the stress distribu
ents of the joint under service load conditions. However,
the following limitations:

. It underestimates the effective stiffness of a slab by
ing the width of the "slab column" to the bearing len
the floor slab in calculating areas of discrete v
"columns." However, analytical investigations[2] i
that additional plank length beyond the edge of a wal
participates in transferring vertical load from the up

2. It does not consider the use of hollow-core slabs and tional stiffness provided by the grout in the slab cor the connection region.

3. It permits determination of stresses in the elastic r not the load capacity of a joint. Also, the method consider the effect of wall reinforcement or the po of a splitting failure when high strength grout is use

Prestressed Concrete Institute Method 3[5], is based mainly conducted by the Danish Structural Research Center. Their expression seems valid, but is applicable only if grout strengt the joint and the wall concrete strength are similar.

5.2 Proposed Design Procedures

5.2.1 Interior Joints

Vertical compressive load applied to the upper wall is tr to the lower wall through the grout column and the f ends. A greater part of the load is carried by the gro and slabs carry the rest. Ultimate load, P_u, can be into two parts as follows:

$$P_u = P_g + P_s$$

where
P_u = joint strength
P_g = amount of load transferred through th column
P_s = amount of load transferred through th slabs

The amount of load transferred through slabs can be inc cores are filled. It should be noted, however, that, not represent the load capacity of an ungrouted connecti

ned. Strength of an ungrouted connection will, usual higher than P_s. This strength can be determined d the bearing area of slab ends and the compressive stre r slab concrete.

proposed method limits the maximum useable grout st and thus, ensures that joint capacity is controlled by hing rather than wall splitting. The maximum useable ngth, and consequently joint capacity can, however, sed by selecting proper joint variables, such as grout a ngths, wall reinforcement, and by filling the slab efore, high strength grout can only be used effectively s use high strength concrete, they are reinforced against , and the slab cores are filled with grout.

d on the maximum useable grout strength, f_u, the fo ession for capacity of interior horizontal joints was dev

$$P_g = K\, P_u$$

$$P_s = (1 - K)P_u$$

basic principles,

$$P_g = t\, L\, f_u$$

e t = width of the grout column - in this case (76 mm),

L = horizontal length of grout column,

f_u = maximum useable strength of grout defi follows: compressive strength of grou or wall concrete, f'_c, whichever is les not more than 4000 psi (27.6 MPa), unle walls are reinforced against splitting a cores are filled with grout,

load transferred through the grout
was found to increase linearly fr
value of 0.65 for a grout strength
(17.24 MPa) to a value depending
of grout in the joint, f_g.

For simplicity, K can be taken as follows:

$$K = 0.65 + \left[\frac{f_g - 2500}{50,000}\right] \text{ for } f_g \text{ in psi,}$$

$$= 0.65 + \left[\frac{f_g/0.0069 - 2500}{50,000}\right] \text{ for } f_g$$

Therefore, $P_u = P_g/K$

The filled core factor, C, can be used to account for
strength due to increased slab stiffness. The filled
is inversely proportional to the square root of grout
strength, f_g.

Therefore, $P_u = \frac{t\,L}{K} f_u\, C$

where C = filled core factor determined as follows

For filled slab cores:

$$C = 1.4\sqrt{\frac{2500}{f_g}} \text{ for } f_g \text{ in psi, or}$$

$$= 1.4\sqrt{\frac{2500}{f_g/0.0069}} \text{ for } f_g \text{ in MPa,}$$

but not less than 1.0

For unfilled slabs cores:

$$C = 1.0$$

...licable to other types of joints with different geometr... ...erial properties. However, the configuration used in this i... ...ation is representative of horizontal joints used in large ...uctures.

.2 Exterior Joints

...appears from the tests that for exterior joints, most o... ...d applied to the upper wall panel is transferred to the ...l panel through the grout column. Stiffness provided by ...b may, therefore, be ignored.

...refore, $P_u = P_g$

...ed on the experimental study on exterior joints, the foll... ...ression is proposed for determining a conservative value fo... ...nt strength:

$$P_u = t\,L\,f_u\,C \qquad \text{(Eq.}$$

...re P_u = joint strength,

t = width of grout column - in this case 3 in. (76 mm),

L = horizontal length of grout column,

f_u = maximum useable strength of grout define... follows: compressive strength of grout, f... wall concrete, f'_c, whichever is less, but ... more than 4000 psi (27.6 MPa), unless ... cores are filled with grout,

f_g = compressive strength of grout in the joint...

C = filled core factor determined as follows.

...filled slab cores:

$$C = 1.2\sqrt{\frac{2500}{f_g}} \quad \text{for } f_g \text{ in psi, or}$$

but not less than 1.0

For unfilled slab cores:

$$C = 1.0$$

It should be noted that the above expression is based on lim number of tests applied to one type of joint configuration. It not be applicable to other types of joints with different geome cal or material properties. However, the configuration use this investigation is representative of horizontal joints comm used in large panel structures.

Comparison of Measured and Calculated Strengths

ngths for the interior joint specimens were calculated from e PCI Methods and from the proposed design expression. These ared with the measured strengths. The values are listed in Tabl

tressed Concrete Institute Method 1 is based on stress-deform acteristics of the joint components. An increase in grout stre wed due to its confined nature in the joint. However, the m not distinguish between slab cores filled and unfilled. The value of confinement factor is arbitrarily fixed at 2.0. In c ng the load capacities using this method, confinement factors o 1.0 were assumed for slab cores filled and unfilled, respecti hermore, there is no provision for additional joint strength d forced wall panels, or loss of strength due to wall splitting rout crushing in unreinforced wall panels. Consequently, the c d strengths of Specimens J-2, J-3 and B-4 were substantially di from measured strengths.

tressed Concrete Institute Method 2 gives stress distribution ice load conditions only. In calculating the load capacity of j

cimen ber*	Calculated Load Capacity ** (kips)				Meas Stre (ki
	PCI Methods			Proposed Method	
	1	2	3		
B-6	211	286	252	300	34
B-7	249	332	299	351	36
B-5	460	309	275	417	44
B-2	502	334	301	433	46
B-3A	344	445	417	417	44
J-2	761	488	462	411	46
J-3	761	488	462	496	52
B-4	1028	642	628	519	52

Specimens JM-1 and J-1 have been omitted because their fa o poor dry packing. Specimen B-1 has been excluded beca o grout column provided.

able 2 for strength of grout, concrete and other variables.

c equivalent: 1 kip = 4.448 kN

n this method, the stress or load distribution at ultimate wa be the same as at service load. Also, since this method does o account the effect of splitting in the walls, calculated Specimens J-2 and B-4 are overestimated. These specimens h strength grout. Wall splitting occurred before the grout re is no provision for added joint strength due to fi es. Therefore, calculated strengths of Specimens B-2 and erestimated.

stressed Concrete Institute Method 3 is applicable only w wall strengths are approximately equal. For the present te

ween measured and calculated strengths for specimens ... and ...
ever, strength of Specimen J-3 with reinforced wall panels, was u...
imated. Values for grouts with lower and higher strengths are ...
en in Table 8 for comparison. In these specimens, agreement be...
culated and measured strengths is poor.

of all the methods proposed prior to the present research, ...
hod 2, based on elastic analysis of a joint provided the ...
sonable approach for designing interior wall-to-floor connect...
ever, as described earlier in this section, this method gives s...
tribution in the elastic range only, and it does not consider ...
es where joint capacity is limited by wall splitting. Conseque...
use of this method for predicting joint strength is very limited...

proposed design method described in Section 5.2 is based on the ...
t experimental investigation. It predicts the joint capacity t...
o account all modes of joint behavior both under service and inel...
ding conditions. As shown in Table 8, the load capacity calcu...
the proposed method agrees very favorably with the measured ...
engths.

acities for exterior joint specimens were also calculated from ...
posed design expression. A comparison with measured values is ...
Table 9.

Specimen Number*	Joint Strength** (kips)	
	Calculated by Proposed Method	Measured
E-1	236	300
E-2	204	290
E-3	288	280*
E-4	333	380
E-5	325	400

*Specimen E-3 has reduced joint capacity due to poor dry packing.

**See Table 3 for strength of grout, concrete and other variables.

Metric equivalent: 1 kip = 4.448 kN

1 Interior Joints

1. Joint capacity increases with grout compressive str joint strength is controlled by grout crushing. T when the grout strength is less than about 80% c concrete compressive strength.

2. Wall Splitting is not a problem when low-strengt used. However, for unreinforced walls, when the pressive strength exceeds about 80% of wall concre sive strength, wall splitting occurs prior to gro its strength. When the walls are adequately development of full grout strength results in incr capacity. The amount of wall reinforcement requir splitting increases with grout compressive strength.

3. Filling slab cores with grout directly affects strength. For low-strength grouts, joint strengt substantially with filled cores. With medium stre behavior at ultimate load changes from grout crush splitting when slab cores are filled. With both high strength grouts, wall reinforcement limits sp thus, the benefits from filling the cores are utili

4. The quality of dry pack below the upper wall panel nificant effect on the joint strength. Inadequate with voids leads to a substantial loss of joint capa

5. Floor moment and rotation do not have a significan the strength of a wall-to-floor connection.

ior Joints

When grout strength is equal to or less than wall con
compressive strength, joint capacity increases with grout
pressive strength.

Filled slab cores in exterior joints minimize the effec
built-in or accidental eccentricity. Joint strength, how
is not significantly improved.

When grout strength is less than or equal to wall con
compressive strength, wall splitting does not occur.

When the grout strength is greater than the wall strength
is anticipated that wall splitting will occur unless the
are adequately reinforced.

The proposed expression (Eq. B-8) gives conservative value
load capacities for exterior horizontal joints when comp
with the measured strengths.

recommendations for specific analysis techniques and d
re given in Report 5[2].

oss sectional area of grout column

onfinement factor

odulus of elasticity of upper wall panel

odulus of elasticity of dry pack

odulus of elasticity of grout in the joint

odulus of elasticity of lower wall panel

ompressive strength of concrete

ompressive strength of grout in the joint

aximum useable strength of grout for calculating joint strengt

ineness modulus

tiffness factor

orizontal length of grout column

hortening measured over a height ℓ_1 at the lower end of upper
anel (See Fig. 17)

hortening measured in dry pack, total height = ℓ_2 (See Fig. 1

hortening measured in grout column, total height = ℓ_3 (See Fi

hortening measured over a height ℓ_4 at the upper end of lower
anel (See Fig. 17)

hortening measured in grout column over a height ℓ_3' (See Fig.

$\ell_1 + \delta\ell_2 + \delta\ell_3 + \delta\ell_4$ = total joint shortening measured over a
$= \ell_1 + \ell_2 + \ell_3 + \ell_4$ (See Fig. 17)

arge panel

ertical load transferred through grout column

oint strength

hickness of grout column

ertical stress in grout column

ental eccentricity:	An eccentricity which exists result of errors in either the or erection process.
bly:	An aggregate of panels.
ng area:	Area of the wall panel through cal compressive force is app joint; 24 x 8 in. (610 x 203 case.
-in eccentricity:	An eccentricity which exists as exterior joint configuration.
ctions:	A position or region where two o ing components, panels or assem together or united.
ction stiffness: vertical loads)	The sum of stiffnesses of grout "columns" composing a connection
nement factor:	A factor used to allow for incre sive strength of grout, reflect fined nature of material in the
nuity:	The capacity for load transfer or more elements where load is moment, or any combination there
e pattern:	Mode of behavior at ultimate loa
mation:	A change in dimension or shape.

Dry-packed mortar:	A mortar mixture sufficiently dr solidated by heavy ramming.
Ductility:	The measure of a structural (element or joint) ability inelastic deformations, i.e. t the maximum deformation to deformation.
Exterior joints:	Horizontal joints connecting e panels and floors.
Filled slab cores:	Hollow cores of precast conc filled with fluid grout (ext 3-1/2 in. (89 mm) into the cores
Floor moment and rotation:	Moment applied to simulate ac conditions (less than calcula moment).
Floor panel:	Horizontal precast concrete el cally consisting of hollow concrete planks.
Floor plank:	A horizontal precast concret e cally extruded and reinforced wi strength steel. Also known as or hollow-core slab.
Grout:	Mixture of cementitious materi gate to which sufficient water produce pouring consistency w gation of the constituents.

ness ratio:	Ratio of grout column to the total... tion stiffness; also defined as s... factor.
ngth:	Average compressive strength of gro... ured on six 6x12-in. (152x305 mm) cy... Ranges of strength are: Low: 2500 to 4000 psi (17.2 to 27. Medium: 4000 to 5500 psi (27.6 to 37. High: 5500 to 7000 psi (37.9 to 48.
joint:	The zone common to the wall and floo... in a horizontal direction.
of connection:	The ability of a connection to ... loads from one portion or element to... while retaining its structural stabil...
ints:	Horizontal joints connecting inter... panels and floors.
ngth:	The maximum load sustained by a joint...
(LP) structures:	A structural system composed of ... load-carrying elements of large prec... panels with precast floors and r... panels or planks.
l reinforcement:	Minimum transverse reinforcement pro... the ends of wall panels to keep t... from splitting before grout is cr... the joint.
d:	Unfactored normal loading condition.

trength of grout:	See grout strength.
ransverse wall reinforcement:	Optimum amount of reinforcement p the end of wall panels to limit spl
ltimate joint load:	See joint strength.
ltimate load: general)	The maximum load which may be pla connection, member or a structure failure; also, the load at which a unit or structure fails.
all panel:	A vertical precast concrete elem load-bearing or non-load-bearing one-story in height, with lengths ranging from 10' to 45'.
all reinforcement:	See transverse wall reinforcement.

mbly of Specimens

pecimen consisted of precast top and bottom wall panels
concrete hollow-core slabs assembled as shown in Figs. 3

le a specimen, the lower wall block was plastered to the
w-core planks were lowered into position on top of it.
were supported on 2-in. (51 mm) wide elastic bearing pa
the joint. The other ends of floor slabs were temporaril
jacks placed on concrete blocks as shown in Figs. 7 and
g, the screw jacks were replaced with load cells.

plete joint test, the grout in the joint extended about
nto the slab cores to provide continuity. This was accom
crumpled newspapers as "dams" to stop the flow of grou
point. In tests where the slab cores were deliber
the cores were completely blocked at the face using
was then filled with grout.

panel above the joint rested on dry-packed mortar al
thick. The mortar was packed from both sides of the wa
ill the joint.

rials and Fabrication

Floor Elements

w-core slabs used in all series had a design compressiv
000 psi (34.5 MPa). Cross-sectional dimensions are
23.

Wall Panels

st concrete wall panels were used. Top and bottom wall
ical. A cross section is shown in Fig. 24.

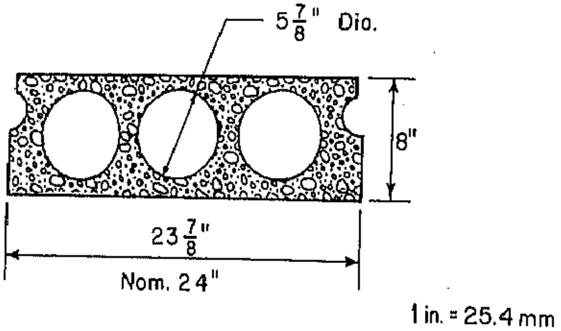


Fig. 23 Slab Cross Section

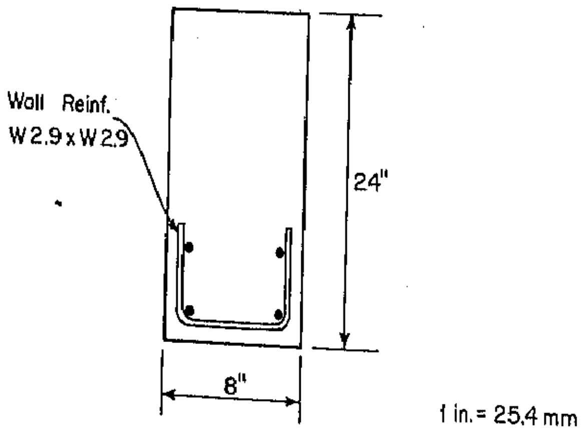


Fig. 24 Wall Cross Section

e size of 3/4 in. (19 mm). The specimens and test cy
ed in the forms under plastic sheets for at least 3 days

Compressive strength of concrete was determined fr
of nine 6x12-in. (152x305 mm) cylinders prior to testing.
re given in Tables 2 and 3.

tests, both wall panels were reinforced at the ends with 6
9 reinforcement to limit splitting. The total amou
ement provided in each wall was 0.116 in.^{2} (75 mm^2).

rout and Mortar

rength was one of the major variables. Tests were mad
rengths of approximately 3000, 5000, and 7000 psi. (20.7
MPa). Actual compressive strengths are listed in Ta

ry tests were made to determine the properties of fine ag
d grout prior to starting the test program on full-scale
s. These tests are described in Appendix D.

in. (25.4 mm) thick dry-packed mortar was placed under t
el. The mixture contained equal parts by weight of
nd Elgin Sand, and just enough moisture to make it wo
metallic packers were used to ensure proper packing of th
r.

edges of grout and dry-packed mortar were covered with
or at least 3 days curing after they were placed. Comp
of dry pack was usually higher than that of wall pane
the joint. A strength of about 9000 psi (62.1 MPa), w
rom the average of six 2x2-in. (50x50 mm) cubes tested at
ximately 5 days.

st specimens were ...
hortening and wall splitting. The layout of instrumentatio
or joint test is illustrated in Fig. 25. Test setup for ext
was similar. Due to the built-in eccentricity of the exterior j
ab was also supported horizontally and the horizontal reactio
ed.

.1 Forces

the case of Specimen JM-1 with long slabs, two sets of load cells
re used to measure the slab end reactions and the applied floor mo
shown in Fig. 5. The slab load was applied with hydraulic ran
rce was measured by a pair of load cells placed between the t
ab and the cross heads on both sides of the connection.

other tests were conducted with short slabs. The support reac
e measured by two 25-kip (111 kN) load cells placed on con
cks under the slabs.

.2 Joint and Wall Shortening

ee 1-in. (25 mm) Linear Variable Differential Transfo
DT)[4] were used to measure shortening of the joint, upper
el and the lower wall panel over a length of about 10 in. (0.2
o, in some tests, an extra LVDT and a strain gage were used o
er side of the joint to measure shortening of the grout column a

.3 Wall Splitting

0.001-in. (0.025 mm) dial gages were used to measure upper and
l splitting. The gages were mounted to detect changes in wall t
s. Tensile strains were also sensed underneath the upper wall
two 67-mm gage-length electrical strain gages[3] mounted as
Fig. 25.

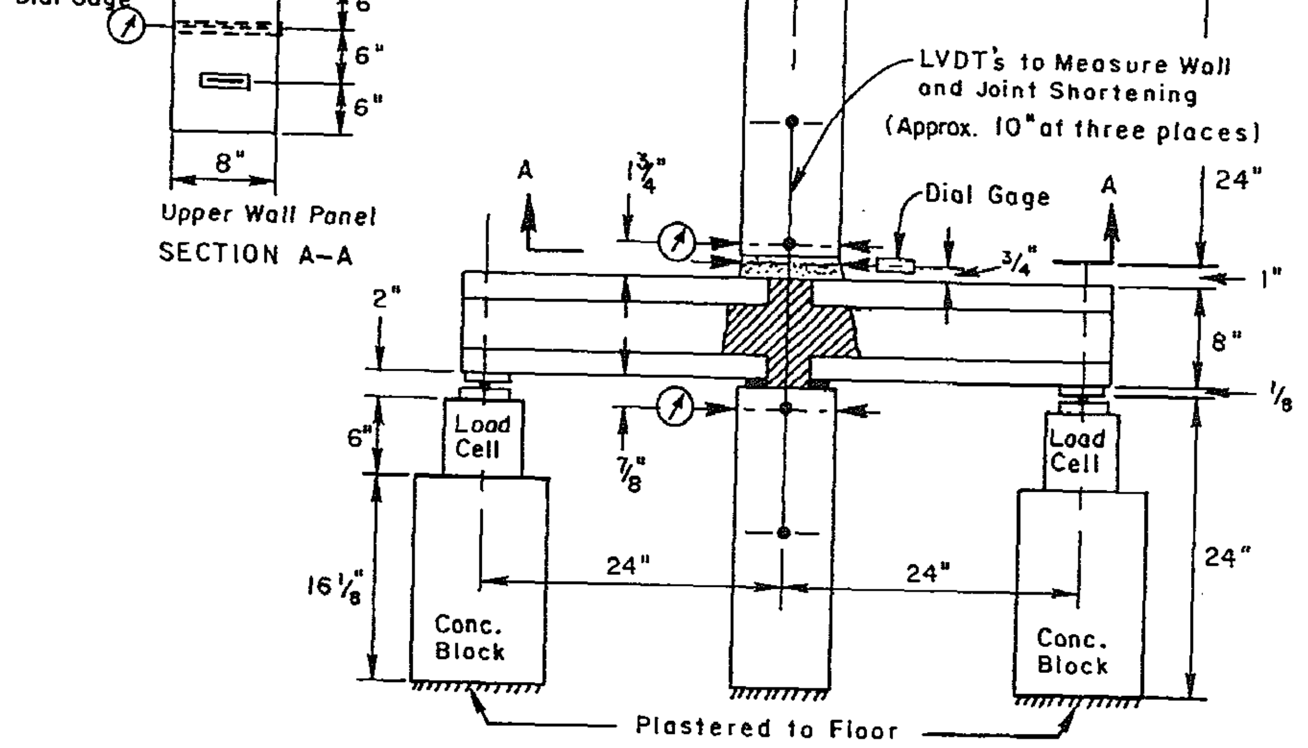


Fig. 25 Layout of Instrumentation for Interior Joint Test

l load cells, LVDT's and strain gages were connected to the D
ta Acquisition System (DDAS). A mini computer was interfaced
AS system to obtain simultaneously a magnetic tape record and pr
raw data. The dial gages were recorded manually.

est Procedure

setup and loading arrangement are shown in Figs. 7 and 8 for ir
xterior joints, respectively. A 1,000,000 lb. (4448 kN) t
e was used to apply the vertical compressive force. Load was a
h a 1-in. (25.4 mm) thick steel plate plastered to the top
wall panel. The specimen was centered below the loading head.

ens were loaded incrementally to destruction. The loading head
e was locked by inserting wedges after two or three load stages.

pecimen was loaded in about 25 increments. The size of increme
d as the ultimate strength was approached.

each load increment, measurements of all data were recorded.
identified and marked on the specimen in the order of their form
her characteristics that occurred in the specimen after the init
cracks were recorded also. The maximum load sustained was cons
strength of the joint.

Program

objective of the tests was to determine the propertie
ill both longitudinal and transverse joints in LP structu
strengths were measured on 2-in. (51 mm) cubes, 2x4-in. (
and 6x12-in. (152x305 mm) cylinders at 7 and 28 days.
tests were made on 2x4-in. (51x102 mm) cylinders at the s

variables included were:
ggregate to cement ratio.
ater to cement ratio.

program consisted of two series. Series A used an ag
io, by volume, of 3.0. Series B used a ratio of 2.25.
he water to cement ratio, by weight, was varied from
unts of materials used for each batch of grout are show
e there was always some free moisture present in aggre
e adjustment was made each time to the amount of water

TABLE 10 - GROUT CONSTITUENTS AND MIX WEIGHTS

Materials	Bulk Unit Weight lb./cu. ft.	Mix Weights, lb.	
		Series A	Series B
Type I Cement	94	40	40
Elgin Sand F.M. = 3.10	101	130	96
Water	62.4	Varied	Varied

Metric Equivalents: 1 lb. = 4.448N
1 cu. ft. = 0.02832 cu.m.

---

ely, Construction Engineer, Construction Methods Se
Senior Structural Engineer, Structural Development
ement Association, Old Orchard Road, Skokie, Illinois.

out 48 hours after fabrication. The specimens were then demolde
in the moist room until about two hours before testing. The er
rical specimens for compression tests were capped with high str
g compound and the caps were allowed to cure at least one hour
mpression testing. The strengths of grout were determined fro
e of at least four specimens.

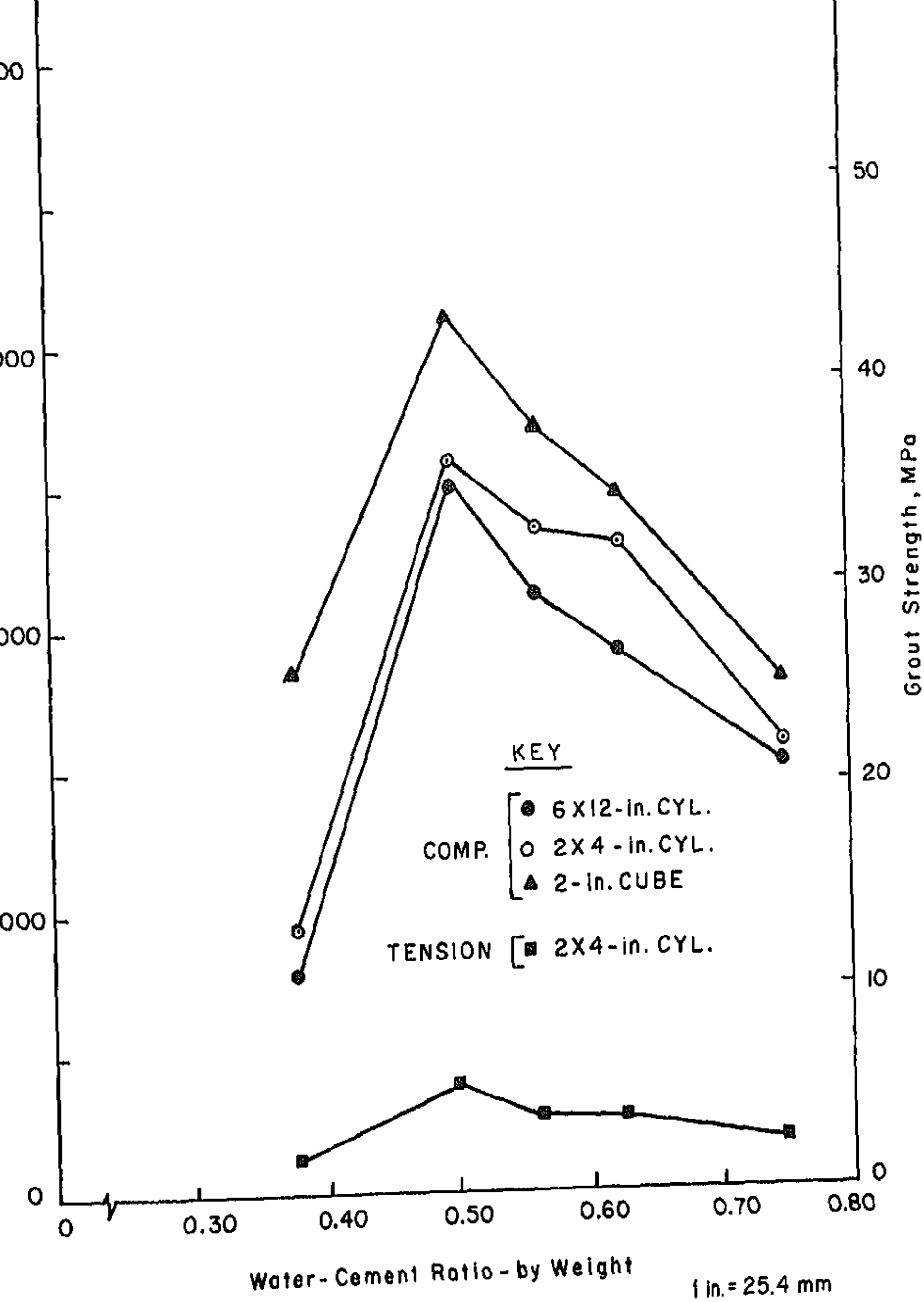
est Results

e grout strength versus water-cement ratio are shown in Fig
h 29. Average values for each series are given in Table 11.

ests indicated that when the grout was either too stiff or too
esults were inconsistent. When the water-cement ratio was low,
n was a problem, and inconsistency resulted from a nonuniform
igh water-cement ratio, the mix was very fluid. Compaction wa
ed. However, heavier particles tended to settle down leaving a
of water on top. Also, the mix had to be constantly agitated
ecimens were being cast.

on these tests, it appears that the most appropriate water-
to achieve good workability and consistency would be in the ran
0.75 with an aggregate-cement ratio of 3.0, and between 0.37
for an aggregate-cement ratio of 2.25.

were also made to determine the fineness modulus, moisture con
eight, and specific gravity of sand that was used as fine aggrega
mix. The results of tests on fine aggregate are tabulated in
he gradation curve shown in Fig. 30, was plotted from the resul
rd sieve analysis. The material conformed to the
ements.(7)



. 26 Strength versus Water-Cement Ratio at 7 Days for Series

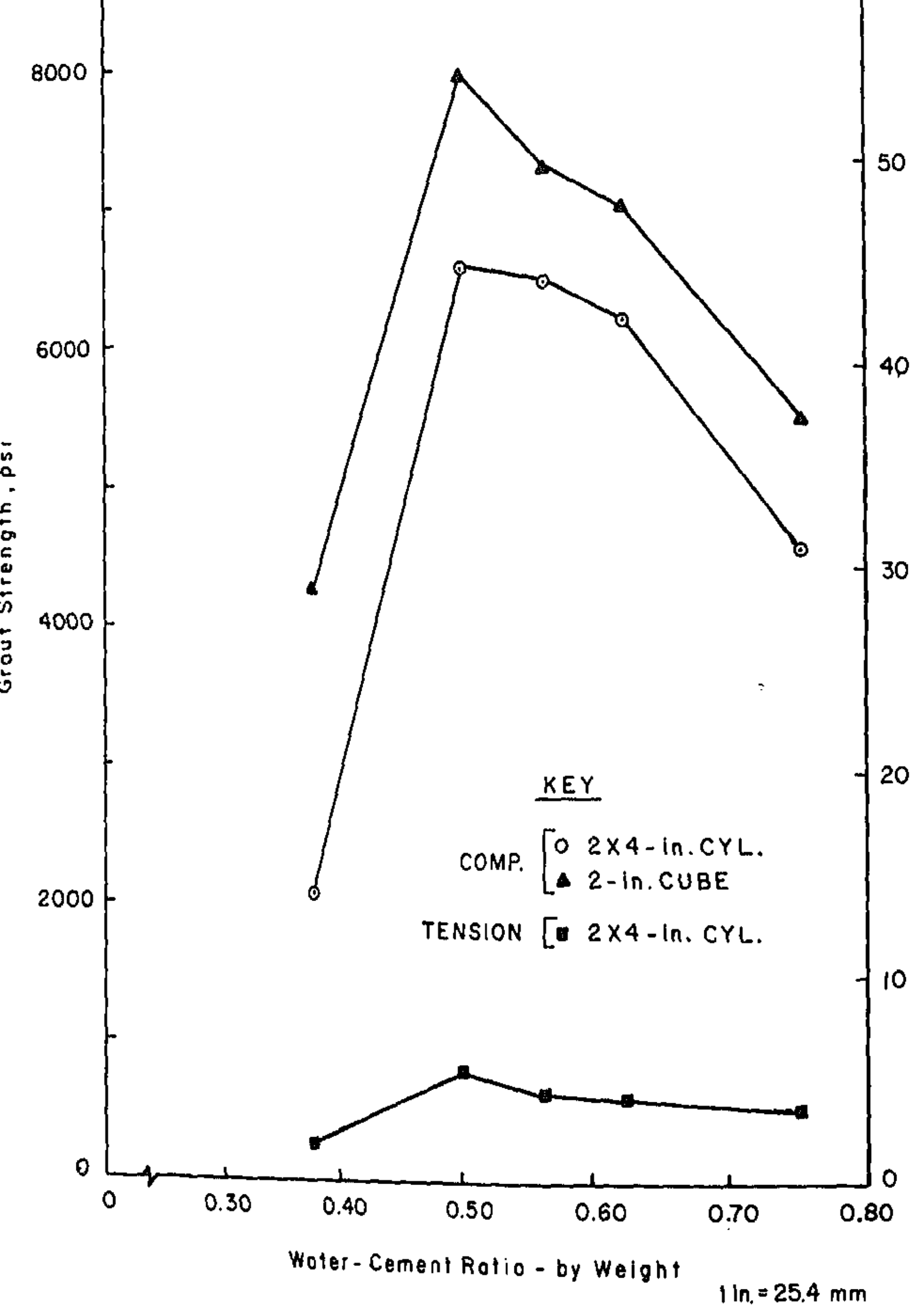
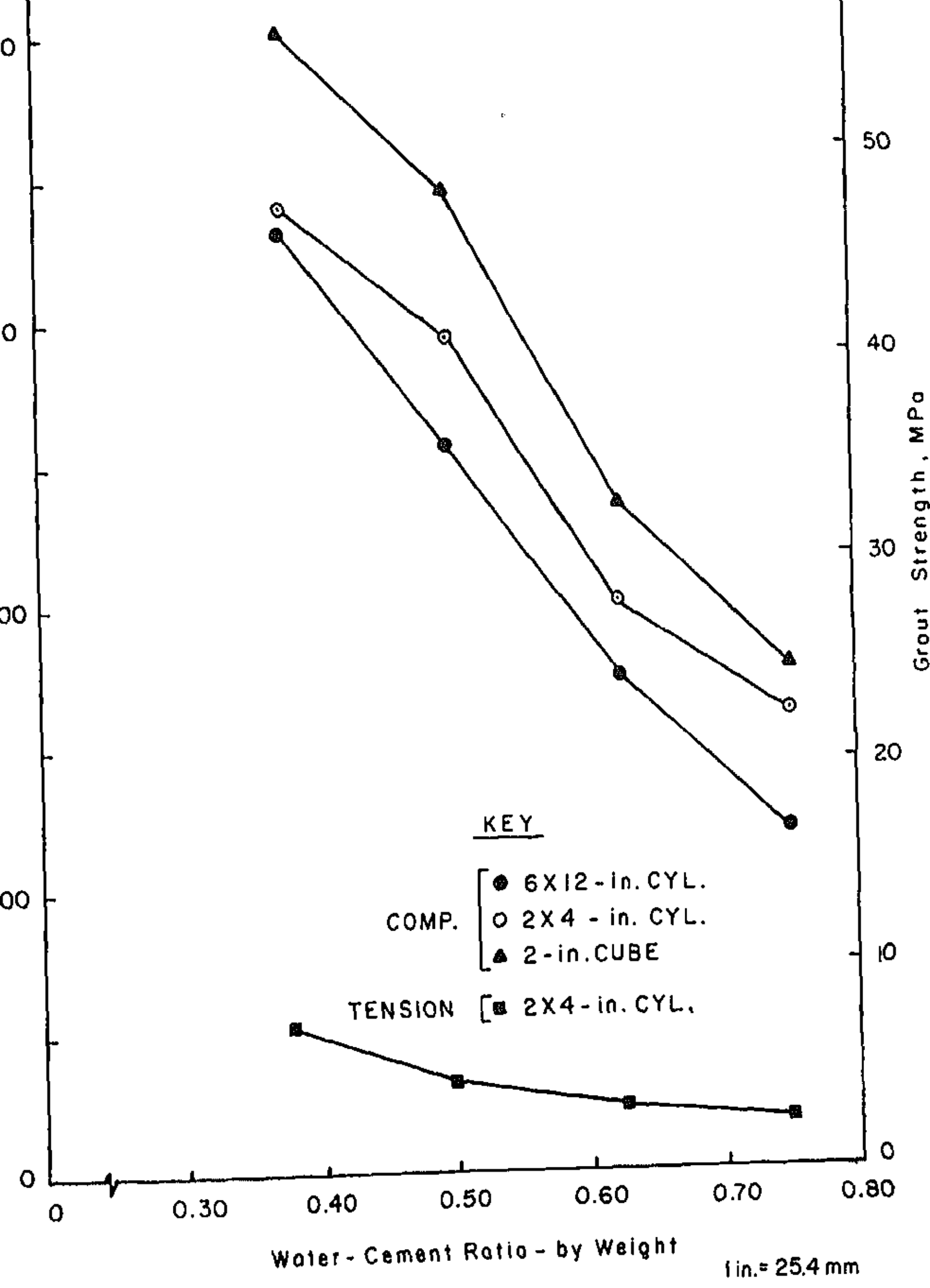


Fig. 27 Strength versus Water-Cement Ratio at 28 Days for Serie



28 Strength versus Water-Cement Ratio at 7 Days for Series B

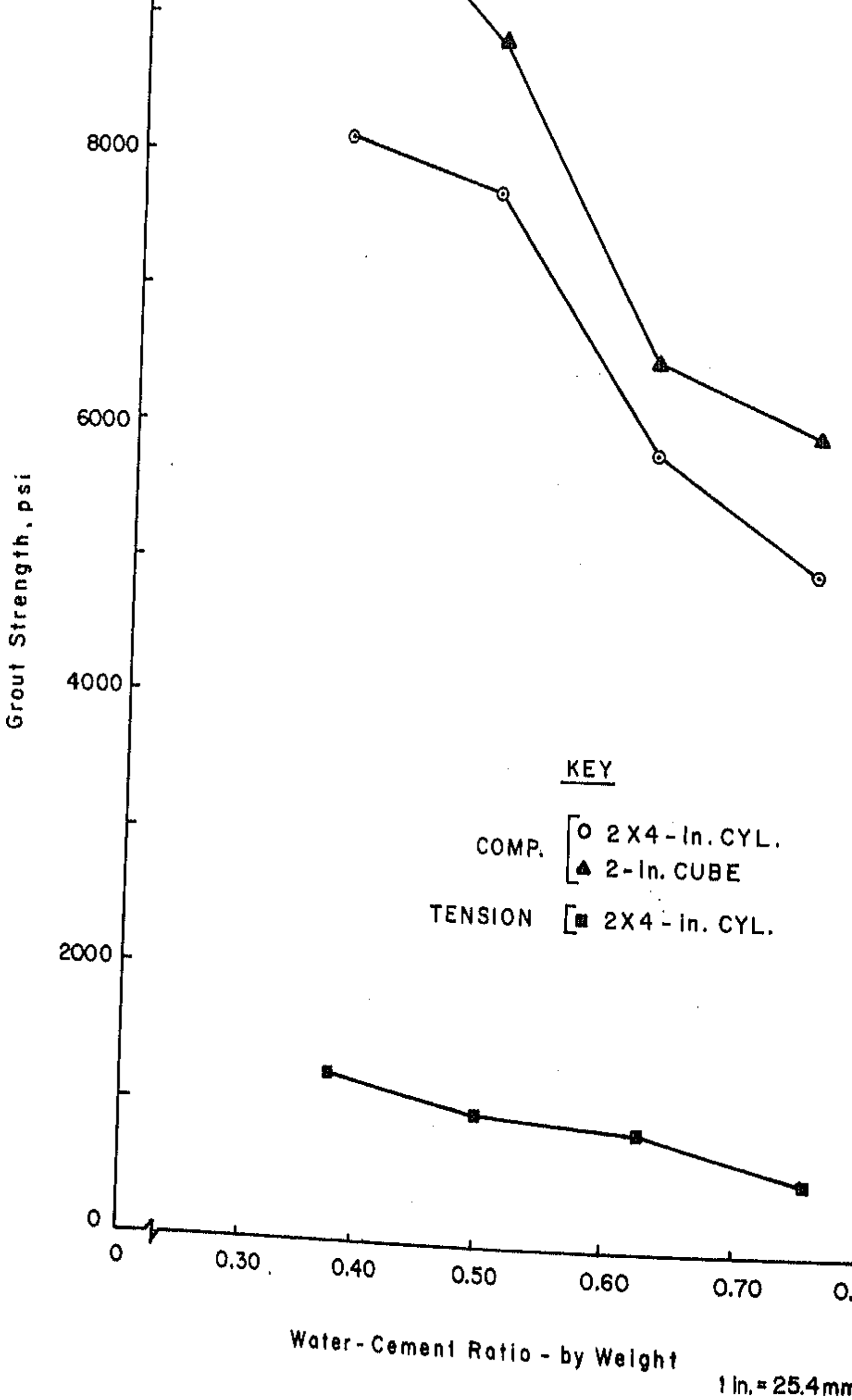


Fig. 29 Strength versus Water-Cement Ratio at 28 Days for Se

Aggregate-Cement Ratio (by volume)	Water-Cement Ratio (by weight)	Average Compressive Strength* (psi)					Strength* (psi)	
		2-in. Cubes		2x4-in. Cyl.		6x12-in. Cyl.	2x4-in. Cyl.	
		7 Days	28 Days	7 Days	28 Days	7 Days	7 Days	28 Days
3.0	0.375	3700	4240	1880	2070	1550	250	270
	0.500	6220	7890	5190	6510	5040	770	800
	0.562	5490	7220	4720	6490	4250	530	650
	0.625	4990	6960	4610	6170	3880	510	620
	0.750	3610	5460	3180	4510	3060	360	540
2.25	0.375	8050	10000	6830	8050	6640	1040	1240
	0.500	6970	8750	5920	7660	5130	650	980
	0.625	4710	6410	4030	5790	3550	480	860
	0.750	3570	5900	3240	4940	2400	350	510

* Average strength of at least four specimens.

Fineness Modulus		3.10
Moisture Content		3.14 %
Specific Gravity		2.73
Unit Weight (pcf)	Natural	101
	Dry	115

Metric Equivalent: 1 pcf = 16.02 kg/cu.m

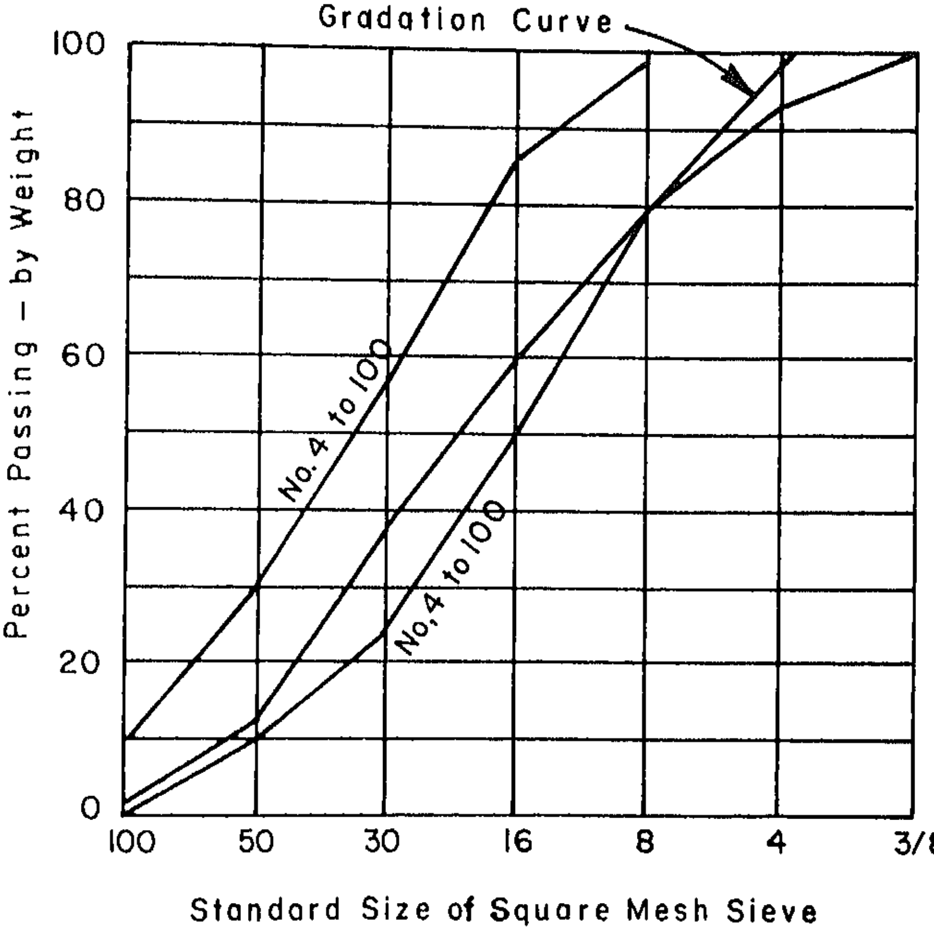


Fig. 30 Gradation Curve for Fine Aggregate

This investigation was carried
land Cement Association under the direction of Dr. H. G. Russe
Structural Development Section and Dr. W. G. Corley, Director,
Development Department. Particular credit is due B. Wm. Fullhar
Graves, for their assistance in the manufacture and testing of th
and Wm. Hummerich, Jr. for instrumentation. Mr. M. Finte
Advanced Engineering Services Department, Portland Cement Ass
overall project supervisor. Mr. D. M. Schultz, Senior Structur
Structural Development Section contributed significant directio
in design of the test specimens, conduct of the tests and inter
the data.

ral Response to Normal and Abnormal Loading Conditions
struction of Large Panel Concrete Structures, Office
ment and Research, Department of Housing and Urban Dev
ton, D.C., August 1976. Also PCA Publication EB92.

, D.M., Johal, L.S., Derecho, A.T. and Iqbal, M., "
Topics," Design and Construction of Large Panel
res, Office of Policy Development and Research, Depa
and Urban Development, Washington, D.C., January 1979.
tion EB95.

ad, E., Hanson, N.W., Kriz, L.B., and Kurvits, O.A., "F
t Methods of PCA Structural Laboratory," Journal of the
Association, Research and Development Laboratories, Vo
Vol. 1, No. 3, 1959, pp. 35-41; PCA Development Bulletin

N.W., Hsu, T.T.C., Kurvits, O.A., and Mattock, A.H., "F
t Method of PCA Structural Laboratory - Improvements
of the Portland Cement Association, Research and De
ries, Vol. 3, No. 2, May 1961, pp. 27-31; Vol 7, No. 1
. 2-9; and Vol. 7, No. 2, May 1965, pp. 24-38; PCA De
D91.

mittee on Precast Bearing Wall Buildings, "Consideratio
of Precast Bearing Wall Buildings to Withstand Abnorma
of the Prestressed Concrete Institute, Vol. 21. No.
76.

truction and Construction Evaluation of Mortars for
ed Unit Masonry," (C780-74) American Society for Tes
s, Philadelphia, part 16, 1977, pp. 436-451.

d Specification for Concrete Aggregates," (C33-77)
for Testing and Materials, Philadelphia, part 14, 1977,
7.

[The] following list will enable readers to convert the U.S. and Canadian customary values of measur[ement] in this publication to SI (International System) units, the currently recommended form of the [metric syst]em. Also included are a few conversion factors that do not conform strictly to SI but are com[monly used] in some 'metric' nations. The proper conversion procedure is to multiply the specified U.S. [or Can]adian customary value by the conversion factor exactly as given below and then to round to the [appropria]te number of significant digits desired. For example, to convert 11.4 ft. to meters: 11.4 x 0[.3048 = 3.]472 which rounds to 3.47 meters for an accuracy of two significant digits. Do not round eithe[r value bef]ore performing the multiplication, as accuracy would be reduced. A complete guide to the SI sy[stem and] its use can be found in ASTM E380, Standard Metric Practice Guide (A Guide to the Use of SI--t[he Inte]rnational System of Units).

convert from	to	multiply by
gth		
n (in.)	centimeter (cm.)	2.54
h (in.)	meter (m.)	0.0254
t (ft.)	meter (m.)	0.3048
d (yd.)	meter (m.)	0.9144
a		
are foot (sq.ft.)	square meter (sq.m.)	0.0929
are inch (sq.in.)	square centimeter (sq.cm.)	6.452
are inch (sq.in.)	square meter (sq.m.)	0.0006
are yard (sq.yd.)	square meter (sq.m.)	0.836
ume		
ic inch (cu.in.)	cubic centimeter (cu.cm.)	16.39
ic inch (cu.in.)	cubic meter (cu.m.)	0.0000
ic foot (cu.ft.)	cubic meter (cu.m.)	0.0283
ic yard (cu.yd.)	cubic meter (cu.m.)	0.7646
lon (gal.) Can. liquid**	liter	4.546
lon (gal.) Can. liquid**	cubic meter (cu.m.)	0.0045
lon (gal.) U.S. liquid**	liter	3.785
lon (gal.) U.S. liquid**	cubic meter (cu.m.)	0.0037
ce		
	kilogram (kgf)	453.6
	newton (N)	4,448.
d (lb.)	kilogram (kgf)	0.4536
d (lb.)	newton (N)	4.448
ssure or Stress		
per square inch (ksi)	kilogram per square centimeter (kg/sq.cm.)	70.31
d per square foot (psf)	kilogram per square meter (kg/sq.m.)	4.882
d (force) per square foot (psf)	pascal (Pa.)†	47.88
d per square inch (psi)	kilogram per square centimeter (kg/sq.cm.)	0.0703
d (force) per square inch (psi)	pascal (Pa.)†	6,895.
(Weight)		
d (lb.) avdp.	kilogram (kg)	0.4536
2,000 lb.	kilogram (kg)	907.2
n	kilogram (kg)	0.0000
(weight) per Length		
per linear foot (klf)	kilogram per meter (kg/m.)	0.0014
d per linear foot (plf)	kilogram per meter (kg/m.)	1.488
per Volume (Density)		
d per cubic foot (pcf)	kilogram per cubic meter (kg/cu.m.)	16.02
d per cubic yard (pcy)	kilogram per cubic meter (kg/cu.m.)	0.5933
erature		
ee Fahrenheit (deg. F.)	degree Celsius (C)	$t_C = (t_F - 32)/$
ee Fahrenheit (deg. F.)	degree kelvin (K)	$t_K = (t_F + 459.$
gy		
ish thermal unit (Btu)	joule (J)	1,056.
watt-hour (kwh)	joule (J)	3,600,000. E
r		
epower (hp) 550 ft.-lb./sec.	watt (W)	745.7
city		
per hour (mph)	kilometer per hour	1.609
per hour (mph)	meter per second (m./s.)	0.4470